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A SUMMARY OF ENVIRONMENTAL AND TUNA FISHING INFORMATION OF THE LINE ISLANDS

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ABSTRACT

This paper provides a brief historical resumé and description of the Line Islands and reviews much of the published information available on the climate, oceanographic climate, planktonic surveys, and tuna resource in that region. Of significance is the delineation of a major fishing ground for deep-swimming tunas in the central equatorial Pacific. Attention is focused on tuna fishing trials by several types of gear and the results obtained. Change in abundance of tuna as a function of the variation in the wind-driven ocean circulation in that region is also discussed.

INTRODUCTION

The fishery for tropical tunas in the eastern Pacific Ocean began in California prior to World War I as an outgrowth of the albacore, *Thunnus alalunga*, fishery, which started about 1903. The eastern Pacific is one of the major tuna producing areas of the world, where two species of tuna--yellowfin, *T. albacares*, and skipjack, *Katsuwonus pelamis*, are fished intensively by nationals of South, Central, and North America. Because of heavy exploitation, the yellowfin tuna fishery in the eastern Pacific has been under international management since 1966 (Joseph and Calkins 1969). However, it has not been demonstrated that there is a need to implement measures to conserve the other species of tunas in the eastern Pacific.

The demand for canned tuna continues to increase and the eastern Pacific tuna fishing fleet continues to grow. But it is obvious that little increased production can be expected from yellowfin tuna there. The eastern Pacific fleet must supplement its yellowfin tuna catch by fishing on tuna stocks capable of sustaining greater fishing pressure than is now being imposed on them. Among the possibilities are yellowfin tuna stocks outside the regulated area, and the bluefin tuna, *T. thynnus*, and skipjack tuna stocks throughout the Pacific.

It is reasonable to expect, therefore, that the eastern Pacific fleet will intensify their fishing effort in areas outside the Commission's Yellowfin Regulatory Area (CYRA). Among the areas now being considered is the Line Islands. For this reason, it is appropriate to bring together in summary form, for the benefit of the fishing industry, such information, published or unpublished, as may be useful in planning future fishing ventures to the Line Islands.

DESCRIPTION OF THE ISLANDS

The Line Islands, shown in Figure 1, are small, low, semi-barren coral atolls that run south by southeast on both sides of the equator between long. 150° and 163°W north of the Society and Cook Islands (Tudor 1972). Extending from Kingman Reef, which lies about 925 nautical miles south by west of Honolulu at about lat. 6°N, to Flint at lat. 11°26'S, the 11 islands of the Line group straddle the equator.

Five islands in the group are usually identified as the northern Line Islands. These are Kingman Reef and Palmyra Island, both belonging to the United States, Washington and Fanning Islands, attached to the British Colony of Gilbert and Ellice Islands, and Christmas Island, which is formally a condominium jointly claimed by the United States and the United Kingdom.

Among the southern Line Islands, Jarvis Island belongs to the United States, whereas Malden, Starbuck, Caroline, Vostok, and Flint Islands are British possessions administered directly by the High Commissioner for the Western Pacific.

Palmyra, Fanning, Christmas, and Caroline have lagoons; the remaining seven have the familiar fringing reef. Christmas Island has an open saltwater lagoon and many ponds of varying salinity. All the islands in the group are either privately or government-owned; therefore, fishing vessels would require permission to land or fish in the islands' coastal waters.

KINGMAN REEF

This bare, triangular reef, shown in Figure 2, measures
2 roughly 14 km (9 statute miles[2]) long and 8 km (5 mi) wide and encloses a deep lagoon. It is at the northern end of the Line Islands group at lat. 6°24'N and long. 162°24'W (Tudor 1972). The reef, located 1,714 km (925 mi) south of Honolulu, was discovered in 1798 and annexed by the U.S. in May 1922. Between 1934 and 1938, the sheltered lagoon at Kingman Reef served as a half-way station for flying boats on airmail service between Honolulu and Pago Pago, American Samoa. Kingman Reef is still under the control of the U.S. Department of Navy but there is no active military installation. The reef covers an area of about 0.3 sq km (0.1 sq mi) (Bryan 1951).

PALMYRA ISLAND

Discovered in 1802, Palmyra Island (Fig. 3) is located 61 km (33 mi) southeastward of Kingman Reef at lat. 5°52'N and long. 162°06'W (Tudor 1972). Palmyra was formerly a part of the Hawaiian Islands but was excluded from the boundaries of Hawaii by the Hawaii Statehood Act and is now the responsibility of the U.S. Department of the Interior. Palmyra consists of about 50 islets totaling about 6 sq km (1,470 ac) of land. The main harbor is in West Lagoon, which is entered by a channel on the southwest side of the atoll; both channel and harbor will accommodate vessels drawing about 4 m (13 ft). Roads and causeways built during World War II, when the U.S. Navy had 6,000 men stationed there, are run down and overgrown with vegetation.

The atoll is only about 2 m (6 ft) above sea level. As a result of a high annual rainfall, the island is wet and humid and covered by dense vegetation. There are, however, many clear, sunny days (Bryan 1941).

WASHINGTON ISLAND

Washington Island (Fig. 4), discovered in 1798 and annexed by Great Britain in 1889, lies 222 km (120 mi) southeast of Palmyra at lat. 4°43'N and long. 160°25'W (Tudor 1972). The atoll, about 5.5 km (3.4 mi) long by 1.9 km (1.2 mi) at its greatest width, has a circumference of about 14.5 km (9 mi) and a land area of less than 10.4 sq km (4 sq mi) (Bryan 1941). The land is covered with a dense growth of coconut palms and underbrush. Most of the beach is of fine sand and the fringing reef in most places is not more than 183 m (200 yd).

The atoll is included in the Gilbert Islands Colony. According to Tudor (1972), the land is all owned by Fanning Island Plantations Ltd.; about 78 Gilbertese are employed in copra production. There is an anchorage at the west point of the island. Bryan (1941) reported that the bank off the west point has an area of about 5 sq km (2 sq mi) with depths between 9 and 36 m (5 and 20 fm). Vessels may anchor on this bank but only in calm weather. A new landing located on the south side about 0.8 km (0.5 mi) from the southwest point is reportedly a better anchorage.

A distinctive feature of Washington Island is the fresh-water lagoon on the eastern half of the island (Bryan 1941). The western half has two peat bogs that occupy the former lagoon, as evidenced by the presence of marine shells and white coral sand on the lagoon bottom and beneath the layers of peat.

The lagoon, about 2.8 km (1.5 mi) long by 1.3 km (0.7 mi) wide, is 1 m (3 ft) above sea level and averages 1.5 m (5 ft) deep although it is reported to reach a depth of 9 m (30 ft) in some places (Bryan 1941). The water level in the lagoon is maintained by rainfall, which on Washington is heavier than on Fanning Island. The climate at Washington is much the same as that at Fanning where high temperatures are tempered to some extent by the trade winds.

FANNING ISLAND

Fanning Island (Fig. 5), forms the Line Islands Administrative District together with Washington and Christmas islands (Tudor 1972). Chave (1971) describes it as a beautiful atoll located at lat. 3°55'N, long. 159°23'W, approximately 139 km (75 mi) southeast of Washington Island. The island has a circumference of about 51 km (32 mi) and has a land area of about 32.5 sq km (12.5 sq mi). Composed of three islets enclosing a shallow lagoon, the atoll is 19 km (12 mi) long and 10 km (6 mi) wide.

British Cable and Wireless established a cable station on Fanning in 1902 to serve as a connecting link of the Pacific cable between British Columbia and Suva, Fiji Island, but abandoned it in 1963. In 1966, the University of Hawaii, Honolulu, Hawaii, acquired a lease from the former Gilbert and Ellice Islands Colony for the abandoned cable station land and its 15 buildings (Chave 1971). A 760-m (2,500-ft) airstrip has since been added to the island by the University.

All the land on the island is owned by Fanning Island Plantation Ltd., a subsidiary of Burns, Philp and Company, Ltd., Sydney, Australia. About 12.5 sq km (3,100 ac) of the total land area are under cultivation for copra production. The island is inhabited by 600 Gilbertese copra workers.

English Harbor provides sheltered anchorage for vessels up to 1,000 tons. However, the lagoon entrance channel at English Harbor is subject to strong tidal currents, with speeds up to 7 knots (13 km/h). Effects of this current can be felt as far as a mile offshore, particularly on the outflowing ebb tide. Passage through the channel should only be attempted at slack periods in the tidal cycle. Another calm weather port is at Whaler's Anchorage.

CHRISTMAS ISLAND

Situated 284 km (153 mi) southeast of Fanning Island at lat. 1°55'N and long. 157°20'W, Christmas Island (Fig. 6) is the largest coral atoll in the world (Jenkin and Foale 1968). The atoll, which covers 640 sq km (247 sq mi) of which 321 sq km (124 sq mi) is land, is 2,474 km (1,335 mi) south of Honolulu. The greatest length is 53 km (33 mi) from north of Northwest Point to Southeast Point; the maximum southwest-northeast distance is 31 km (19 mi). Christmas Island is shaped like a lobster claw whose jaws open to the northwest. Within the claws is a semicircular lagoon which occupies 160 sq km (62 sq mi). The lagoon is shallow, and has numerous coral heads; it should only be entered by small boat, preferably with the assistance of someone with local knowledge.

The island was discovered in 1777 by Captain James Cook, annexed by Great Britain in 1888, and included in the former colony of the Gilbert and Ellice Islands in 1919 (Tudor 1972). British control of the island was disputed by the United States in 1936-38, and although recognizing that Christmas Island is presently administered by the Gilbert Islands Colony, the United States has not relinquished its claim on the island.

There are two settlements on the island, London and Paris, but the latter is deserted and in ruins. These settlements are located to the north and south of the entrance channel to the main lagoon, respectively. A third settlement, called Poland, located near the Southwest Point, has been permanently occupied since June 1966.

In addition to the lagoon, Christmas Island has about 500 lakes with salinities varying widely between $35^{\circ}/_{\circ\circ}$ and $330^{\circ}/_{\circ\circ}$. At present, the Christmas Island Plantation, which is government-owned and operated, has 20 sq km (5,000 ac) under cultivation for copra production. The island has an excellent network of paved main roads and hardpan secondary roads. A 1,800-m (6,000-ft) runway is at the northern end of the island.

JARVIS ISLAND

Lying 371 km (200 mi) southwest of Christmas Island and a little more than 41 km (22 mi) south of the equator is Jarvis Island (Fig. 7) at lat. 0°22'S and long. 160°03'W (Bryan 1941). This atoll, which is small, low, and basin shaped, measures 2.9 km (1.8 mi) long by 1.6 km (1 mi) at its greatest width (Bryan 1941). Discovered in 1821, it wasn't until 1857 that the American Guano Company claimed the island and started removing large quantities of guano (Tudor 1972). Jarvis was abandoned in 1879. Annexed by Great Britain in 1889, the island was leased to the Pacific Phosphate Company but apparently never worked. The United States claimed the island in 1935 with no objection from Britain. The island has been used since then as a weather station; a settlement on the west side, called Millersville, consisted of some stone and wooden houses and a radio shack. Now under control of the Department of the Interior, the island was most recently occupied during the International Geophysical Year (1957-58).

The highest point around the rim of the island is 7 m (23 ft) and portions of the east rim are less than 3.6 m (12 ft) (Bryan 1941). The rim is narrow and encloses an extensive basin; however, there is no permanent lagoon. A narrow fringing reef, roughly 90 m (100 yd) wide, surrounds the steep beach. On the west side is a narrow channel blasted through the reef. This makes landing comparatively easy.

MALDEN ISLAND

British-owned Malden Island (Fig. 8), located at lat. 4°03'S and long. 154°59'W, lies 446 km (241 mi) south of the equator and 691 km (373 mi) southeast of Jarvis (Bryan 1941). It is a triangular, flat coral island measuring about 8 km (5 mi) long by 6 km (4 mi) wide and the east central portion is occupied by a very large saltwater lagoon. The land area is given as 43 sq km (10,700 ac) with an additional 36 sq km (9,000 ac) of lagoon.

The ridge that encloses the lagoon is nowhere more than 8 to 9 m high (25 to 30 ft) (Bryan 1941). The shore is surrounded by a narrow fringing reef with the greatest width variously estimated between 180 and 550 m (200 and 600 yd). A steep beach rises from the reef. The anchorage is precarious because of deep water off the edge of the reef. Despite the existence of a small pier near the south end of the west shore, landing on the island is often difficult.

Malden is somewhat barren with only stunted vegetation growing there (Tudor 1972). At the time of its discovery in 1825 about 40 stone archeological ruins were found on the island. Subsequent discovery of guano deposits on the island in 1840 led an influx of several Australian guano companies over the years who worked the island profitably for 70 years. The island has been unused and unoccupied since 1927.

Malden is warm, but the climate is pleasant despite its uniformity (Bryan 1941). Temperature varies between 24° and 37°C (75° and 99°F) and averages 29°C (85°F). Violent storms are rare.

STARBUCK ISLAND

Situated at lat. 5°37'S and long. 155°53'W, Starbuck Island (Fig. 9) is 200 km (108 mi) south by southwest of Malden Island and 623 km (336 mi) south of the equator (Bryan 1941). Starbuck is a low, flat, coral atoll about 8.8 km (5.5 mi) long and 3.7 km (2.3 mi) wide. It is barren and without any palms. The greatest height along the beach crest is about 4.5 m (14 ft); within the crest the island is depressed with small, shallow saltwater lagoons near the eastern end. Land area is about 2.6 sq km (1 sq mi).

The island, discovered in 1823 and worked for guano for many years beginning in 1870, has been unoccupied and unworked since 1920 (Tudor 1972). At present, Starbuck is a British possession.

The steep beach of Starbuck Island is surrounded by a fringing reef which is about 914 m (1,000 yd) wide (Bryan 1941). There is no safe anchorage. A break has been blasted in the reef near the West Point, but landing is difficult and often dangerous.

CAROLINE ISLAND

Caroline Island (Fig. 10), a small atoll measuring 9.6 km (6 mi) long and less than 1.6 km (1 mi) wide, lies 778 km (420 mi) southeast of Starbuck Island and 1,104 km (596 mi) south of the equator (Bryan 1941; Tudor 1972). This British-owned atoll, located at lat. 9°58'S and long. 150°13'W, has more than 20 islets strung along a reef, which encloses a shallow lagoon. There is no passage through the connecting reef.

Some of the islets are 5-6 m (15-20 ft) high and most are covered with groves of coconut palms and underbrush (Bryan 1941).

The reef, which extends for about 1.6 km (1 mi) off the southwest and southeast points, is not exposed at low water (Bryan 1941). On the side of the island that is exposed to the weather, the sea breaks heavily. There is no anchorage, but landings can be made at high water through a narrow break in the reef off the northwest point of the southern islet; at low water, one must wade across the reef in knee-deep water.

Caroline Island, discovered in 1795, was once inhabited by Polynesians and there was a settlement of about 30 people on the southern islet in 1868 (Tudor 1972). Native temple platforms and graves containing adzes have been found on the two northern islets (Bryan 1941). Water can be found by digging. The climate is warm but pleasant with temperatures rather uniform. During much of the year, the island is under the influence of the southeast trades. Showers may be sudden particularly at night.

VOSTOK ISLAND

Located at lat. 10°06'S and long. 152°23'W, Vostok Island (Fig. 11) is a low, uninhabited triangular atoll approximately 232 km (125 mi) west of Caroline Island and 1,121 km (605 mi) south of the equator (Bryan 1941). The island is distinguished only by a dense central clump of buka trees (Pisonia), which reach a height of about

25 m (80 ft) above sea level. According to Bryan (1941), this type of vegetation is very distinctive; the canopy is so dense that no other plants will grow beneath the buka trees. Because of decaying leaves and branches, the soil is rich in humus and usually damp around the bases of the soft, massive tree trunks.

Vostok is about 1.3 km (0.8 mi) long, occupies an area less than 2.6 sq km (1 sq mi), and is completely surrounded by a platform reef which is 90 m (100 yd) or more wide and awash at low water (Bryan 1941). There is a boat passage through the reef at the southwest corner of the island but no anchorage (Tudor 1972). Discovered in 1820, Vostok was claimed by the United States under the Guano Act in 1856 but the claim was never pressed. Between 1873 and 1943, Vostok was worked sporadically for guano and copra. At present, the atoll is a British possession.

FLINT ISLAND

Flint Island (Fig. 12) is a narrow island 4 km (2.5 mi) long and tapering toward both ends from a greatest width of 0.8 km (0.5 mi). It is located at the extreme southern end of the Line Island group at lat. 11°26'S and long. 151°48'W and is 1,270 km (685 mi) south of the equator and 159 km (86 mi) south by southeast of Vostok Island (Bryan 1941). This flat atoll is well wooded and is entirely surrounded by a narrow fringing reef which extends for nearly 1 km (0.6 mi) off the northern point of the island (Bryan 1941). A boat passage has been blasted through the reef leading to a landing place on the western side (Tudor 1972).

Flint, discovered in 1801, is British territory. According to Bryan (1941), the original vegetation of this island has been practically destroyed and the land was intensively cultivated for copra production. Flint also had some guano deposits, but these have long been worked out.

CLIMATE

Information on weather and sea conditions in the region of the Line Islands is useful in planning future fishing ventures; therefore, such information has been brought together from various sources and presented in summary form in the following sections. A detailed and useful discussion of weather and sea in the equatorial Pacific may be found in [U.S.] Bureau of Commercial Fisheries (BCF) (1963).

In the central equatorial Pacific, the climate is characterized by extreme uniformity with the exception of rainfall (Bryan 1941). All the coral atolls in the Line Islands lack elevation and, therefore, never become cold. The atolls are also surrounded by great expanses of water and subjected to nearly continuous trade winds. As a result, the temperature is never very high.

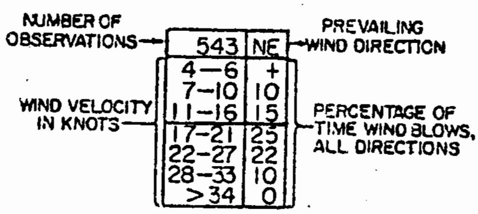
TEMPERATURE

Over the years, the annual mean temperature in the central Pacific has ranged between 23.8°C (75°F) and 28.8°C (84°F) (Bryan 1941). Only rarely does the average maximum temperature rise above 32.2°C (90°F). On "cold" winter days, the temperatures may fall below 21.1°C (70°F). According to Bryan (1941), the highest reported temperature was 41.1°C (106°F) on Christmas Island. On the other atolls, the temperature seldom exceeds 37.8°C (100°F) and then only for a few hours.

WIND SPEED AND DIRECTION

In the equatorial Pacific, wind velocity and sea conditions are two of the most important weather elements affecting fishing operations. Fishing vessels operating in the equatorial region may be subjected to periods of sustained wind velocities of 20-30 knots when fishing is not possible (BCF 1963). These periods of high winds are caused by the strengthening of the easterly trade winds associated with the north and south movement of the intertropical convergence zone.

-16 Figures 13 to 16, adapted from U.S. Navy Hydrographic Office (1959), Marine Climatic Atlas of the World, show wind and sea conditions between lat. 30°N and 20°S and between long. 70°W and 180° (BCF 1963). January, April, July, and October were selected as being representative of each of the four seasons. In the figures, the blocks and triangles represent areas and island stations, respectively, where observations were made. The hatched block indicates Weather Ship Station November. The figure in the upper left in each set of data is the number of observations; the wind velocity ranges in knots are given below that. At the upper right, the prevailing wind direction is given. The percentages of time the winds, from whatever direction, are within the indicated velocity range are also given. For example:



In the figures, winds of 0-4 knots are omitted and wind frequencies of less than 0.5% are indicated by a plus sign (+). As a convenience for tuna fishing vessel operators, data on winds greater than 17 knots are set off by a line so that the proportion of time wind and sea conditions may seriously affect fishing operations can be quickly estimated.

The following descriptions of wind and sea conditions accompanying each figure (Figs. 13 to 16) were obtained from BCF (1963).

January winds (Fig. 13)

"Fresh to strong winds occur in several areas, mainly between latitudes 10° and 30°N. The area between Hawaii and longitude 130°W. experiences strong easterly and northeasterly winds about 30-40 percent of the time. The Tehuantepec region has experienced winds up to gale force about 30 percent of the time; gale-force winds (>34 knots) occur about 6 percent of the time. Other areas to the south of the Equator and westward have reported strong tradewinds (>16 knots) averaging about 20 percent of the time."

April winds (Fig. 14)

"Winds limiting fishing operations may be encountered in the Gulf of Tehuantepec about 6 percent of the time. Strong winds may also occur about 600-900 miles southeast of the Hawaiian Islands about 68 percent of the time. High easterly and southeasterly trade wind velocities also occur in the region of 0°-15°S. near 130°W.; here velocities in excess of 16 knots occur from 25-73 percent of the time."

July winds (Fig. 15)

"The maximum trade wind zones noted in April change very little, except for an eastward extension of strong winds to include the region near 10°S. and 110°W. Here easterly and southeasterly trades blow above 16 knots from 16-30 percent of the time. Increased easterly wind velocities are observed also in the Phoenix-Samoa-Tokelau Islands area."

October winds (Fig. 16)

"North winds exceed velocities of 16 knots about 24-25 percent of the time in the Tehuantepec region. Wind velocities from 17-27 knots prevail about 48 percent of the time in an area about 600-900 miles southeast of the Hawaiian Islands, and strong easterlies occur in an area from 5° to 15°S at 100° to 130°W. (east of the Marquesas) about 33-35 percent of the time."

Sea conditions may be estimated from Table 1, which gives the maximum time and fetch required for winds to produce waves of a given height and the length of the resulting waves (BCF 1963). For example, a sustained wind of 20 knots blowing for a minimum of 19 h over a distance of 222 km (120 mi) will generate a 2.4-m (8-ft) sea with 47.2-m (155-ft) wave crest intervals.

-20 Figures 17 to 20, adapted from U.S. Weather Bureau (1938), Atlas of the Climatic Charts of the Oceans, show average wind velocities computed for the equatorial region, irrespective of direction (BCF 1963). In general, these figures show the shifting of the areas of maximum prevailing wind velocity by season. In winter (Fig. 17), the maxima occur in two distinct belts. One is at lat. 10°N and the other at about 10°S. Although the maximum spring trades persist in the northern hemisphere in a broad belt, there is a slackening of the maximum to the south of the equator except near long. 100° and 120°W (Fig. 18). Figure 19 shows that the summer winds increase south of the equator near long. 110°W, but to the north the northeast trades are diminished somewhat. By fall (Fig. 20), wind velocities are somewhat higher in the southern latitudes between long. 90° and 140°W.

Between the trade wind zones is an atmospheric low-pressure trough which is associated with rising warm moist air and weak variable winds. This zone is the doldrums, which marks the climatic equator. In January, the trough is near lat. 5°N at long. 150°W, at about the equator near long. 160°W, and near lat. 5°S at long. 170°W. But by July, it is farther north at about lat. 5°-9°N.

According to Seelye (1950), the percentage of east wind in the Line Islands area appears to be associated with the amount of rainfall. Table 2, which gives the surface wind summaries for 1914 and 1924, shows that at Malden Island the winds came from the east only 38% of the time in a year of extremely heavy rainfall. By contrast, in a year of extremely light rainfall, the wind blew out of the east 88% of the time.

RAINFALL

The variability of rainfall is the most significant feature of the climate in the Line Islands (Bryan 1941; Seelye 1950). It is governed largely by the location and strength of the doldrums (Barkley
e 3 1962).[3] In the northern Line Islands, rainfall is greater than the world's average, reaching 300 cm (118 in.) or more per year near lat. 5°N at long. 170°W and over 249 cm (98 in.) per year near lat. 5°N at long. 150°W. In the southern sections, the minimum rainfall of about 76 cm (30 in.) per year occurs near lat. 5°S at long. 150°W.

The average annual rainfall in the Line Islands region is shown in the map in Figure 21. Isohyets (line of equal rainfall) are drawn for 152, 229, and 305 cm (60, 90, and 120 in.). Areas with less than 152 cm (60 in.) are the dry zones; those with more than 305 cm (120 in.) are the wet zones. Bryan (1941) classified Kingman Reef, Palmyra, Washington, and Fanning Islands as wet (Fig. 22). The dry islands were Jarvis, Malden, and Starbuck Islands. Christmas, Caroline, Vostok, and Flint Islands were in the intermediate area between the wet and dry zones. There is, however, a considerable overlap in annual rainfall between the wet and dry zones. For example, on Fanning which is relatively wet, the annual rainfall has varied from 119 cm (47 in.) to 531 cm (209 in.), whereas on Malden, which is relatively dry, it has varied between 10 cm (4 in.) and 239 cm (94 in.).

The variability in annual and monthly rainfall for Palmyra, Washington, Fanning, Christmas, and Malden Islands is demonstrated in Figure 23. Table 3 shows that the average annual rainfall at Fanning was 213 cm (84 in.) whereas that at Malden reached only 71 cm (28 in.). But the variability in rainfall was only 41% at Fanning compared with 67% at Malden. Furthermore, the percentage frequency of dry months was usually higher at Malden than at Fanning. Seelye (1950) found that for the years examined, 52% of all months were dry at Malden compared with only 30% at Fanning. At Malden, the rainfall is usually meager; a few exceptionally wet months accounted for most of the total rainfall.

The months of the highest and lowest average rainfall are

24,25 also given in the maps in Figures 24 and 25. According to Figure 24, the month of highest average rainfall is in March at Kingman Reef, Palmyra, Starbuck, Caroline, Vostok, and Flint, in April at Washington, Fanning, Jarvis, and Malden, and in May at Christmas. The month of least average rainfall is September at Kingman Reef, October at Palmyra, Washington, Starbuck, Caroline, Vostok, and Flint, and November at Fanning, Christmas, Jarvis, and Malden (Fig. 25).

The most detailed climatological data on any of the islands in the Line group come from Christmas Island. Jenkin and Foale (1968), who surveyed the coconut-growing potential of Christmas Island, did a detailed analysis of the climatological data collected there. Some of the results of their study are presented in the sections that follow.

CLIMATE AT CHRISTMAS ISLAND

Christmas Island, which lies within the equatorial dry zone that extends as a narrow belt across the central and eastern Pacific Ocean, is moderately dry (Jenkin and Foale 1968). Its climate may be summarized as follows:

Rainfall

Christmas Island is considered moderately dry with an average annual rainfall of about 87 cm (34 in.). However, the annual rainfall, given in Table 4, has varied widely from very dry (18 cm or 7 in.) to wet (262 cm or 103 in.). About 5 years out of every 20, the annual rainfall is likely to be below 51 cm (20 in.) and in about 8 out of every 20, it is likely to be above 99 cm (39 in.). March, April, and May were usually the wettest months and October and November the driest. The annual rainfall total at Christmas Island can be predicted from the rainfall in the first months of the wet season at locations where the wet season begins earlier than at Christmas Island. A highly significant positive correlation ($r = +0.66$) existed between the annual rainfall at Christmas Island and the sum of the rainfall for the months of December of the previous year and January of the same year at Fanning Island. The regression equation is

$$x_1 = 510 + 31.6\ y_1$$

or $$x_2 = 20.09 + 1.25\ y_2$$

where x_1 = annual rainfall at Christmas Island, mm

x_2 = annual rainfall at Christmas Island, inches

y_1 = sum of rainfall for December of the previous year and January of the same year at Fanning Island, mm

y_2 = sum of rainfall for December of the previous year and January of the same year at Fanning Island, inches

Temperature

There was little variation in temperature from month to month (Table 5). Monthly maximum temperatures were usually highest in November and December whereas the monthly minima were lowest in June. Diurnal variation was also very small with maximum temperatures usually occurring at about 1400 h and minimum at about 0600 h.

Atmospheric Pressure

Atmospheric pressure varied only slightly not only from month to month but also diurnally. The pressure was usually lowest at 1500 h and highest at 0800 h. The average mean monthly atmospheric pressure at 0800, 1400, and 2000 h in 1953-65 is given in Table 6.

Relative Humidity

Table 7 gives the data on relative humidity at Christmas Island. September, October, and November had the lowest relative humidity, whereas March and April had the highest. Diurnally, the lowest humidity usually occurred between 1200 and 1400 h and the highest between 0000 and 0600 h.

Cloud

The cloud cover was generally consistent with the relatively low rainfall occurring on Christmas Island, reaching its highest percentage in March-April and lowest in September (Table 8). Consistently greater cloud cover was experienced at 0800 and 1400 h than at 2000 h.

Sunshine

Because no sunshine data were available for Christmas Island, Jenkin and Foale (1968) calculated hours of sunshine from cloud cover (Table 9). They estimated that the average number of hours of sunshine for the whole year was 9.5 h/day. The greatest number of hours usually occurred in September and the least in April.

Wind

The average wind speed at Christmas Island showed little variation not only by time of year but also by time of day (Table 10). January usually had the highest wind speed and May the lowest. Diurnally, winds were generally higher at 1400 h than at 0800 or 2000 h. Periods of calms were rare; they accounted for less than 2% of all observations. The wind direction was predominantly due east throughout the year and winds from the southwest and west were very rare. The northeast winds constituted only a small percentage of the total but they were important as the main rain-bearing winds. The infrequent westerly wind was usually accompanied by very heavy rain as a result of severe atmospheric disturbance. Christmas Island lies outside the Pacific hurricane belt.

OCEANOGRAPHIC CLIMATE

A review of the oceanographic observations for this region can be found in Barkley (1962,/ see footnote 3). His text, intended only as a review of salient features, is briefer than a complete discussion of the oceanography of the area warrants; however, Barkley provides an excellent bibliography where additional information and detailed treatment of certain features may be foudd.

The following sections discuss the horizontal and vertical distribution of temperature, salinity, oxygen, and phosphate, surface currents, upwelling, and the equatorial undercurrent in the Line Islands region.

TEMPERATURE

Figure 26 shows the sea-surface temperature in 1954-61 at Christmas Island (Barkley 1962,/ see footnote 3). The daily observations at Christmas Island were smoothed by Fourier analysis of 15-day mean values. The figure illustrates that surface temperature went through seasonal and longer term changes at Christmas Island. Waters around Christmas Island were characterized by year-to-year changes in temperature which were as great as, or greater than, the regular seasonal changes (Barkley 1962,/ see footnote 3). In 1956 and 1958, when there was unusually warm water off the American coast, the Christmas Island temperatures reflected the change with a rapid increase in temperature early in 1957, followed by a gradual decrease to lower values in subsequent years.

Seasonal changes in sea-surface temperatures on a larger scale can be seen by examining the monthly sea-surface isotherms in the vicinity of the Line Islands. Figures 27a to 27ℓ, adapted from U.S. Navy Hydrographic Office (1944), World Atlas of Sea Surface Temperatures, show the surface water isotherms between lat. 30°N and 20°S and between long. 120°W and 170°E. The seasonal shifting of the isotherms latitudinally can be seen by examining the position of the 28°C (80°F) isotherm. In February, it was close to the northern Line Islands at about lat. 7°N between long. 155° and 160°W, but by September it was positioned farther north at about lat. 20°N in the vicinity of the Hawaiian Islands.

Temperatures also reveal the changes that occur at the surface across the main features of the equatorial zonal circulation in the vicinity of the Line Islands. Figure 28 depicts the surface temperature along long. 150°W plotted against latitude across the equatorial current systems in the central Pacific Ocean (Austin 1954a). For reference, the major surface currents are shown in Figure 29. By examining temperature sections, Austin found that the North Equatorial Current extended south to about lat. 10°N, the Equatorial Countercurrent was between lat. 10° and 5°N, and the South Equatorial Current extended from lat. 5°N to the southern limit of the section. The striking features of the temperature section were the rise in surface temperature along the countercurrent and the decrease at lat. 1°S where the equatorial divergence is centered. The cooler surface water here reflected not only the mixing of deeper waters with those at the surface but also advection from the east in varying degrees (Austin 1960).

To further demonstrate the upward movement of cooler water at the equator, the vertical distribution of temperature in the Line Islands in the form of two north-south sections was reproduced in
0 Figure 30. Because temperature is the major determinant of density in the equatorial Pacific, the slope of the isotherm was a good indicator of the density distribution and, therefore, of the equatorial current structure (Barkley 1962, see footnote 3). For example, the downward slope of the isotherms north of lat. 10°N was associated with the westward-flowing North Equatorial Current. At the equator, the presence of cooler water at the surface resulted from vertical mixing. Two separate physical processes were involved in the mixing process (Austin 1960). One was related to divergence of the surface water under the influence of winds with an easterly component. The other was mixing by the winds. Divergence brought water of high density, lower oxygen content, and somewhat higher plant nutrient content to the surface at this latitude. The relationship between temperature and variation in nutrients
1 (phosphate) at the sea surface near the equator is shown in Figure 31. The tongue of cold water along the dark shading indicates masses of high nutrient waters.

The divergence of surface water and the accompanying upwelling which were associated with the equatorial current system produced considerable variation in the depth of the thermocline in the vicinity of the Line Islands. Figure 32 shows that north of the equator between long. 150° and 160°W, the thermocline varied between 30 and 213 m (100 and 700 ft) (Austin 1960). At or near the equator, Austin found it generally difficult to get an objective determination of the thermocline depth because in this region, the bathythermograph (BT) traces often showed either more than one inflection of the curve or a continuous negative gradient from the surface to the maximum depth of the BT trace. This region is indicated in shading in Figure 32. Temperature sections showing the variation in the depth of the thermocline in a north-south
,34 direction along long. 158°W can be seen in Figures 33 and 34. The depth of the thermocline varied widely. Figure 35 shows typical BT traces for various regions crossed in August-December 1951.

Austin (1960) also demonstrated a rapid east-west deepening of the thermocline between long. 125° and 160°W. To illustrate, temperature-depth sections from BT's taken at eight positions along the equator are shown in Figure 36. The top of the thermocline was at 150 m (492 ft) near long. 155°W but was found at only 50 m (164 ft) near long. 125°W. The thermocline deepened slightly east of long. 120°W.

SURFACE CURRENTS

The Line Islands are situated almost entirely within the Equatorial Countercurrent and the South Equatorial Current (June 1951). The North Equatorial Current, which remains in the northern hemisphere as it moves across the Pacific, often extends southward to about lat. 8°N in the vicinity of Kingman Reef. The South Equatorial Current flows on both sides of the equator and reaches northward to about lat. 5°N roughly in the vicinity of Washington Island. Lying between the two westerly flowing equatorial currents is the Equatorial Countercurrent flowing eastward at velocities up to 102 cm/sec (2 knots) at the surface. The countercurrent moves farther north of the equator during the northern summer, when it is strongest.

Charts of monthly surface currents around the northern Line
37
te 4 Islands, shown in Figures 37a to 37ℓ,[4] were obtained from U.S. Navy Hydrographic Office (1950), Atlas of Surface Currents, Northwestern Pacific Ocean. The following description of the speed and direction of surface currents around the northern Line Islands is from Barkley (1962, see footnote 3)

In January-February, the countercurrent appears quite weak and there is a slight intensification of the South Equatorial Current. In March, the surface currents from north of lat. 8°N and south of lat. 5°N flow west and northwest at speeds of 18 to 28 km/day (10 to 15 mi/day) with some values as high as 37 km/day (20 mi/day). In between these latitudes, there is the eastward flowing countercurrent with speeds of less than 18 km/day (10 mi/day). In April, there is almost no trace of the countercurrent at the surface; the surface flow is almost all westerly with some northward component. In the north, the general flow is estimated to be 18 km/day (10 mi/day) with speeds up to 37 km/day (20 mi/day) near the surface. Conditions in May resembled those in March. In June, the easterly flow occurs near lat. 5°N in the west and at lat. 6°-7°N in the east; current speeds of between 28 and 37 km/day (15 and 20 mi/day) are less common in the westerly equatorial currents, but higher velocities occur in the region of the countercurrent, which becomes well developed in July at the surface near lat. 5°-9°N. Velocities of over 28 km/day (15 mi/day) are common. The westward flow near Christmas Island is more intense with speeds of 37 km/day (20 mi/day). Currents in August-October are similar to those in July. The countercurrent diminishes in intensity as the year progresses, with other currents remaining steady.

The generally accepted concept of a zonally oriented flow pattern of the South Equatorial Current between the equator and the countercurrent has been modified by Murphy and Shomura (1972). They argued that the circulation between the equator and the countercurrent is exceedingly complex and as yet imperfectly known. The evidence examined suggested that the region between long. 120°W and 180° is not a single east-west system with respect to identity of its water. Rather, the water flow near the equator differs from the usual concept in that empirical measurements suggested both a northward and westward motion of the same magnitude. The model proposed by Murphy and Shomura, therefore, considered the circulation in this region as a series of adjacent north-westerly flowing cells (Fig. 38).

UPWELLING

The circulation in a north-south plane in the central equatorial Pacific was discussed by Cromwell (1951, 1953). Examination of meridional sections revealed clearly the well-known equatorial upwelling but did not support the thesis that upwelling was occurring at the northern boundary of the countercurrent. Actually, Cromwell believed that horizontal convergence and sinking were apparently associated with an equatorial front, which separated dense upwelled water near the equator from water of lesser density which was usually found in the surface layer of the South Equatorial Current. The front did not coincide with the northern boundary of the countercurrent. Therefore, he proposed a model based on isentropic principles, which relates the transverse circulation near the equator to the winds. In terms of this model, Cromwell showed that there is a zone of horizontal divergence and an adjacent zone of convergence near the equator. The boundary between north-south convergence and divergence, he hypothesized, shifted latitudinally depending on wind direction (Fig. 39). The divergence feature of Cromwell's model explained the equatorial upwelling whereas convergence produced significant sinking. Figure 40 shows the circulation in a north-south plane across the equator during southeast trade winds.

Briefly, the model proposed that under the stress of easterly winds, the surface water would move in a westerly direction at the equator, but the coriolis force north and south of the equator would tend to deflect the surface water poleward (Sette 1955). As the water moved away from the equator, deeper water would rise toward the surface. When there were northerly or southerly components in the easterlies, asymmetry was introduced and the center of upwelling was displaced. For example, southeast trades would displace the center of upwelling to the south of the equator.

North of the equator, convergence occurred as the denser upwelled water sank between the center of upwelling at the equator and the southern edge of the lower density water of the countercurrent which flows from west to east (Sette 1955). At deeper levels, sinking water may turn southward thus completing a cell, or it may move northward and dive under the countercurrent.

EQUATORIAL UNDERCURRENT

The first clue to the existence of a submerged current near the equator was provided through observations on the drift of longline fishing gear in the central equatorial Pacific. The longline gear, suspended from buoys and floating freely in the water, has the main mass of fishing lines in the lower part of the surface layer (Cromwell, Montgomery and Stroup 1954). Set near the equator a number of times during exploratory fishing cruises, the gear moved eastward in spite of opposing trade winds, currents, and seas at the surface. This suggested that a submerged current was prevalent near the equator. Cromwell et al. (1954) proved the existence of this eastward moving current in the lower part of the surface layer and upper thermocline by using surface and deep drags. The undercurrent is depicted in Figure 41.

PLANKTON

Plant and animal life in the ocean are dependent on the meridional circulation just described. The introduction of nutrients into the euphotic zone by upwelling and vertical mixing near the equator increases the phytoplankton and then the zooplankton population. King and Demond (1953) found that by tropical standards, there was a relatively large standing crop of zooplankton near the equator and in the Line Islands region from Christmas to Palmyra Islands (Fig. 42). In general, in the northern summer (June-November), zooplankton abundance reached a maximum at lat. 2°S and long. 150°W near Palmyra; standing crops of more than 50 cc/1,000 m^3 of water strained were common at this time. In the northern winter (December-May), the area of maximum abundance was about the same, but the standing crop was only between 25 and 50 cc/1,000 m^3. In all cases, standing crops of less than 25 cc/1,000 m^3 were found south of the equator and northwest of the Line Islands.

Figure 43 shows the north-south variation in zooplankton abundance (Cromwell 1953). The data were collected during 11 crossings of the equator between long. 140°W and the 180th meridian, a region where southeast trade winds predominated. Maximum zooplankton concentration was apparently related to the equatorial upwelling, because the peak in abundance occurred at the equator. The bulk of the plankton, however, was displaced slightly north which was consistent with the meridional circulation described by Cromwell (1953).

The middle and right panels of Figure 43 show zooplankton abundance based on net hauls made concurrently with hydrographic stations in January-February 1950 and in July-August 1950, respectively. Cromwell (1953) stated that these distributions showed the influence of a meridional circulation near the equator during a southeast wind when a front was present. The middle panel showed a rather abrupt decrease in zooplankton abundance northward across the front whereas the third panel indicated that the zooplankton was concentrated near the front.

In a subsequent study, Hida and King (1955) discovered other interesting facts about the distribution of zooplankton in the central equatorial Pacific. For example, surface hauls at night yielded significantly greater volumes than day samples, but intermediate- and deep-level hauls showed no significant differences in volume between day and night samples (Table 11). They also concluded that the area between lat. 2°S and 8°N at long. 150°W contained the greatest amount of zooplankton, with a peak in abundance at lat. 1°S.

The results of still other cruises during which plankton samples were collected showed the relationship of zooplankton to the various components of the equatorial current system. Having confirmed earlier findings that zooplankton concentration was greatest in the region of upwelling and divergence (King and Demond 1953), King and Hida (1957) discovered also that the average zooplankton volume for the convergent zone and the countercurrent was greater than for the
4 South Equatorial Current south of the equator (Fig. 44). They reasoned that this asymmetrical distribution may result from the prevalence of southeast trades in the central equatorial Pacific. Furthermore, oceanographic fronts in the transition zone between the equator and the southern boundary of the countercurrent separated areas of high
5 and low zooplankton abundance (Fig. 45).

Zooplankton abundance differed not only in a north-south direction, but also in an east-west direction. King and Hida (1957) showed that within the equatorial region, there was a gradient of increasing zooplankton abundance from long. 180° to 150°W. The west to east gradient correlated positively with average wind velocity but negatively with thermocline depth.

King and Hida (1957) also found a highly significant positive correlation between zooplankton volume and surface inorganic phosphate. The highest concentration of phosphate occurred in the divergent zone at the equator, as did the greatest zooplankton abundance. But when examined by longitude and season, high phosphate concentrations appeared to be inversely related to zooplankton and yellowfin tuna

catches. King and Hida concluded that this type of relationship may be the result of differences in rate of utilization of phosphate
46,47 (Figs. 46 and 47).

TUNA RESOURCE

In the early 1950's it was hypothesized that the equatorial divergence-convergence system 2,200 km (1,200 mi) south of Hawaii would be effective as a large-scale mechanism for producing important concentrations of fish (Sette 1955). Sixteen hydrographic traverses to study the equatorial current system provided data that proved there was indeed an upward movement of water at the equator (Cromwell 1951), accompanied by a greater concentration of zooplankton (King and Demond 1953). The logical next step was to assess the potential tuna resource
8 in this area of enrichment (Fig. 48).

Preliminary reconnaissance of the central equatorial Pacific determined that several kinds of tuna, notably yellowfin and skipjack, constituted a highly promising fishery resource. The sections that follow present some of the results obtained by research and commercial vessels that were engaged in assaying the fish stocks in the central equatorial Pacific through systematic fishing surveys.

BIRD FLOCK AND FISH SCHOOL SIGHTINGS

Pole-and-line and purse seine gear can be used only on surface schools of tuna. Because the majority of surface tuna schools in the central Pacific are located in association with bird flocks, the rate of sightings of bird flocks gives an indication of the relative abundance of tuna schools.

During the cruise of the *Oregon*, Smith and Schaefer (1949) observed that between Palmyra and Jarvis, and between Jarvis and Christmas Islands, there were numerous skipjack tuna schools often associated with large flocks of birds. Skipjack and yellowfin tunas were frequently taken on trolling lines during these runs, but the schools were reported to be very wild and erratic in behavior and could not be chummed to the vessel.

Murphy and Ikehara (1955) summarized sightings of bird flocks and fish schools and found that in the Hawaiian Islands, skipjack tuna was by far the most commonly sighted tuna. In the Line and Phoenix Islands, however, skipjack tuna formed a substantial part of the surface sightings but they were considerably outnumbered by yellowfin tuna. On the other hand, seasonal abundance was remarkably similar
12 among the three island groups studied by Murphy and Ikehara (Table 12).
The peak in abundance of skipjack tuna, yellowfin tuna, and all species
9 combined occurred in June-November (Fig. 49). They suggested that
because of this similarity in seasonal abundancé, factors common to all these island groups were operating. But common factors that might

affect fish abundance in all three island groups simultaneously could not be isolated because these groups were widely separated in space and were affected by different current systems. Murphy and Ikehara suggested that possibly these seasonal cycles merely reflected changes in apparent abundance brought about by fluctuations in bird populations because most tuna schools were located by birds.

Murphy and Ikehara (1955) also found variation in species composition of tuna school sightings with distance from land. In the Line and Phoenix Islands, yellowfin tuna were usually near land whereas skipjack tuna predominated in the semioceanic zone which was between 111 and 334 km (60 and 180 mi) from land (Table 13). In the Hawaiian Islands, all yellowfin tuna schools sighted were close to the islands although skipjack tuna predominated there as well as offshore. Furthermore, they concluded that the rate of sighting in the area immediately surrounding the islands (within 111 km or 60 mi from land) was about the same (1.3 versus 1.8/day) as in the semioceanic areas.

Summaries of bird flock and fish school sightings have also been prepared by Waldron (1964) and Naughton.[5] To illustrate the variation in school sightings not only seasonally but also among years in the Line Islands region, data within the 5° square with the highest amount of scouting effort were summarized (Table 14). The results showed that bird flock sightings were usually lowest in March-May and highest in June-August. And although Waldron (1964) showed no sightings of skipjack tuna schools and a very low rate of sightings for total schools in June-August, Naughton showed that the rates of sightings of both skipjack tuna and total schools were highest in June-August. Charts summarizing sightings of bird flocks, skipjack tuna schools, and total fish schools by time-area units bounded by lat. 30°S and 30°N, and long. 110°W and 120°E are shown in Figures 50a through 50ℓ.

TUNA FISHING TRIALS

In undertaking the development of mid-Pacific tuna resources after World War II, several private and semi-private attempts were made to fish for tuna in the Line Islands (Sette and staff 1954). These exploratory fishing ventures were started with the idea of obtaining quick results by sending skilled fishermen on California-type bait boats to places presumed to be rich tuna grounds. Tuna were caught on each of these ventures, but not in commercial quantities.

In the early 1950's, the Pacific Oceanic Fishery Investigations (POFI) launched an intensive investigation into the fishing potential of the Line Islands. In the following sections, tuna fishing trials in the Line Islands by private, semi-private, and government vessels using various fishing methods are discussed.

Pole-and-Line Fishing

The success of pole-and-line fishing depends entirely on a constant and ample supply of live bait. Many different species of small fish offer possibilities as live bait; however, not all have the qualities that make a small fish a good baitfish. These qualities, brought out and discussed at the Tuna Baitfish Workshop held on 4-6 June 1974 in Honolulu, Hawaii, include availability, behavior when chummed at sea, survival in captivity, fishermen acceptance, color and color pattern, body form, and size.

On exploratory fishing cruises to the Line Islands, species most commonly seen or captured for bait included mullet, goatfish, and milkfish (Fig. 51). At Palmyra Lagoon, Smith and Schaefer (1949) reported that the only fish seen that might be used for bait was small mullet, which occurred in quantities along the beaches. They reported seeing no fish of either the silverside or herring families, day or night. At Christmas Island they found bait in the lagoon and reported seeing large quantities of mullet and goatfish, but no fish of the silverside, anchovy, or herring families. They found some silverside just offshore of the island during night baiting operations. The bait catch at Christmas Island consisted of 30 scoops (about 5 kg or 10 lb of baitfish per scoop) of 15-cm (6-in.) mullet and a few goatfish of similar size.

June (1951) provided additional information on bait resources at Palmyra Island. He indicated that mullet suitable for live-bait fishing was most abundant in East Lagoon. The mullet varied in size from 3 to 15 cm (1 to 6 in.) and occurred in schools varying in size from a few scoops to a hundred or more scoops. Small milkfish (5-8 cm or 2-3 in.) were also found along the beaches. Goatfish (3-10 cm or 1-4 in.) occurred in some quantity in Palmyra's West Lagoon. June interviewed Civil Aeronautics Administration personnel stationed on the island and learned that small mullet were most abundant in summer.

Ikehara (1953) also discussed various attempts to capture bait in the Line Islands by the Pioneer and Calistar, tuna clippers which conducted exploratory fishing in the vicinity of the Line Islands in 1947 and 1949, respectively. In late 1947, the Pioneer caught about 400 scoops of mullet at Palmyra and 200 scoops at Christmas Island. The Calistar, on the other hand, reported very poor baiting, with a catch of only eight scoops of bait-size mullet at Palmyra.

In January-February 1953, the Tradewind, a 24-m (80-ft) Hawaiian sampan was chartered in an attempt at pole-and-line fishing in the Line Islands (Yuen and King 1953). The bait catches, mostly mullet, from this exploratory fishing operation were 242 buckets at Palmyra (about 2 kg or 4 lb of baitfish/bucket), 85 buckets at Fanning (about 5 kg or 10 lb/bucket), and 19 buckets at Christmas Island (7 kg or 16 lb/bucket) (Ikehara 1953; Yuen and King 1953). Data on baiting by research vessels in 1950-51 are given in Table 15.

Tables 16, 17
Footnote 6

Summaries of baiting operations and bait surveys conducted in 1955-64 are given in Tables 16 and 17, respectively (Uchida, undated internal report).[6]

In general, only a limited number of observations on bait have been made in the Line Islands. Baiting operations by both commercial and research vessels have been moderately successful, but based on the results of baiting surveys and operations, it is apparent that bait is not in constant supply in any of the islands in the Line Island group. For example, Ikehara (1953) indicated that in June 1951, only a few aholehole were seen in Fanning Lagoon, but in February 1953 the Tradewind caught a good supply of bait-size mullet there. Ikehara also noted that the catchable bait at Palmyra is usually exhausted after only a few days of baiting.

June and Reintjes (1953) provided an evaluation of tuna-bait resources of Palmyra, Fanning, and Christmas Islands. They concluded that Palmyra's lagoons offer stocks of mullet and other small fish that are suitable as supplemental bait to more desirable baitfish species. Bait surveys at Fanning Island were not sufficiently comprehensive to permit sound conclusions about the relative abundance of baitfish stocks. Small fish suitable as supplemental live bait were available in the lagoon at Fanning, but only small quantities were seen. At Christmas Island, June and Reintjes observed large quantities of bonefish and scattered schools of mullet in the lagoon. Because of the size of its lagoon, Christmas Island is potentially the most important baitfish source in the entire Line Island chain. The reported occurrence of the Hawaiian silverside (or a closely related species) in the lagoon at Christmas Island requires further investigation.

Concerning pole-and-line fishing in the Line Islands, Smith and Schaefer (1949) reported poor results. On runs between Palmyra and Jarvis and between Jarvis and Christmas Islands, the Oregon caught skipjack tuna and yellowfin tuna on trolling lines, but the schools she encountered were wild and erratic and usually could not be chummed to the stern of the vessel. At Jarvis, the Oregon succeeded in fishing a school of "two-pole" yellowfin tuna and caught 15 fish; around Christmas Island, however, only one large school of fish was seen.

In late 1957, the Pioneer caught 6.4 metric tons (MT) [7 short tons (ST)] of yellowfin tuna mostly around Fanning and Christmas Islands (Ikehara 1953). But in February 1949, the Calistar, carrying 1,800 scoops of anchoveta caught at Magdalena Bay before departing for the Line Islands, caught about 45 MT (50 ST) of yellowfin tuna at Fanning Island and 13.5 MT (15 ST) of yellowfin tuna at Palmyra Island. The exploratory fishing cruise of the Hawaiian sampan, Tradewind, produced 6.5 MT (7 ST) of yellowfin tuna at Palmyra Island and 5.9 MT (6.5 ST) at Fanning Island.

Data from Ikehara (1953) showed that less time was expended in scouting and fishing in the Line Islands than in other areas of the central Pacific and that the catch was larger (Table 18). Furthermore, a greater percentage of the fish schools sighted there exhibited behavior that permitted the vessel to get into a chumming position. And consistently greater catches of tuna were made from each school fished. The main obstacle to successful pole-and-line fishing in the Line Islands, then, is a constant and ample supply of live bait.

Purse Seining

The scarcity of live bait in the Line Islands made it desirable to develop an alternate method of capture; therefore, purse seine fishing was attempted there in 1950-51. After five exploratory cruises to this area, Murphy and Niska (1953) reported on the purse seining potential of the Line Islands. The cruise periods were 22 April-7 June 1950; 2-19 September 1950; 1 November-1 December 1950; 11-23 February 1951; and 5 April-12 May 1951. A brief summary of each of these cruises is given below.

22 April-7 June 1950--The _John R. Manning_, research vessel of POFI, predecessor of the National Marine Fisheries Service, scouted 310 h and sighted 12 yellowfin tuna, 8 skipjack tuna, 5 unidentified, and 3 mixed schools during the cruise. Two sets with the purse seine around the tuna schools were unsuccessful.

2-19 September 1950--The Manning scouted Jarvis, Christmas, Palmyra, and Kingman Reef a total of 85 h during this period and sighted eight yellowfin tuna and six unidentified tuna schools. Four sets were made on schools off Christmas Island, but all were unsuccessful.

1 November-1 December 1950--The Manning scouted near Kingman Reef, Christmas, Fanning, Washington, and Palmyra Islands for a total of 226 h and sighted nine yellowfin tuna, seven skipjack tuna, and six unidentified schools. Murphy and Niska reported that the schools were usually close to the islands or too elusive to set on; therefore, only one set was made at Fanning Island and that one failed to produce fish.

11-23 February 1951--On this cruise, the Manning scouted waters off Jarvis, Christmas, Fanning, Washington, Palmyra, and Kingman Reef for 104 h and sighted only one yellowfin tuna, two skipjack tuna, and two skipjack-yellowfin tuna schools. No sets were made on any of the tuna schools sighted during the cruise. Strong winds limited operations to the lee of the islands.

5 April-12 May 1951--The Manning scouted waters near Kingman Reef, Palmyra, Fanning, Christmas, and Washington Islands during the cruise for 208 h and sighted only two yellowfin tuna, two skipjack tuna, and two unidentified tuna schools. Five sets during this cruise were all unsuccessful.

In summary, five trips over a 12-month period to the Line Island were made. The vessel devoted 933 h scouting and sighted 75 schools of tuna, but because of proximity of reefs and wild behavior of the schools, only eight sets were possible. On six of these sets, fish were in the circle as pursing began, but sounded out before pursing was completed. The deep thermocline in this area enabled the tuna schools to sound beneath the net.

Trolling

Trolling offered still another alternative to the ways tuna could be captured in the Line Islands. Not requiring live bait, trolling was used as a secondary and incidental procedure during the normal course of scouting for bird flocks and fish schools on purse seining operations.

In the late spring of 1950, the _John R. Manning_, a research vessel operating out of Honolulu, surveyed the Line Islands with purse seine and trolling gear. Bates (1950), who reported on this trolling survey, selected Kingman Reef and Palmyra, Washington, Fanning, and Christmas Islands for exploration because of their proximity to the upwelling along the equator.

In general, the _Manning_ trolled within 11 km (6 mi) of the islands or reef. Bates (1950) found yellowfin tuna concentrated in the lee of the islands during periods of northeast and east winds. The majority of the strikes on the trolling lines occurred within 4 km (2 mi) of the beach, on and around the reefs and in shoal areas.

Manning circled Kingman Reef along the course line shown in Figure 2 in 3 h (Bates 1950). Off the northwestern coast of Kingman Reef, shown by the shaded area in the figure, *Manning* caught fish

able 19 regularly; the results are given in Table 19. Eighty hours of trolling around the reef produced 373 tuna or 0.79 tuna per line-hour. Bates (1950) also made observations on some large schools of tuna sighted near

ble 20 the reef (Table 20).

Sharks were a considerable nuisance at Kingman Reef (Bates 1950). Gray shark, *Eulamia* sp., 1.5-1.8 m (5-6 ft) in length, followed the *Manning* and frequently struck the lures, even at night. *Manning* landed 14 sharks. A number of tuna and wahoo were damaged by sharks when delays occurred in hauling the trolling lines.

Manning circled Palmyra three times, each circle requiring 2.5 h. Bates (1950) reported that large flocks of birds were usually observed working near the reefs on the eastern and western sections of the island. Large numbers of porpoise were also spotted on the eastern side. Surface trolling was best in the shaded area shown in Figure 3; therefore, most of the trolling was confined to this area. Birds were numerous, frequently flocking together to work over concentrations of food organisms. Tunas were often seen jumping under these fast-moving flocks.

From Table 20, it appears that *Manning*'s catch was relatively poor. Bates pointed out, however, that previous reports by people familiar with Palmyra's trolling potential indicate that poor fishing is not a year-round situation. Actually, the largest single day catch of yellowfin during the entire cruise was made at Palmyra. There, 52.75 h of trolling produced 193 tuna weighing 2.1 MT (4,613 lb). The catch per line-hour reached 0.58 fish.

Figure 4 shows the track of the Manning at Washington Island, which required 3 h to circle. Trolling, confined primarily to the shaded area in the figure, produced catches in numbers and tonnage second only to Kingman Reef (Table 19). In 58.25 h, Manning caught 196 tuna weighing 3.2 MT (7,101 lb). The catch rate here was 0.53 tuna per line-hour.

Manning encountered very few tuna at Fanning Island (Bates 1950). No birds or fish were seen in the 4 h required to circle the island. Therefore, most of the trolling was confined to the shaded area shown in Figure 5. Small schools of yellowfin tuna were encountered off Whaler's Anchorage and only a few fish were caught. On the whole, bird activity was far less than at any of the other areas surveyed. Table 19 shows that 32.5 h were devoted to trolling around Fanning but only 15 tuna were taken. The catch of 0.08 tuna per line-hour was extremely low.

Table 19 also shows that in 62 h of trolling around Christmas Island, 105 tuna weighing 2.1 MT (4,690 lb) were caught at a catch rate of 0.28 tuna per line-hour. Bates discovered that on those days when yellowfin tuna bit well (12 and 13 May), they were feeding at the surface on small, red crab megalop larvae. The disappearance of these crabs was reflected in an abrupt decline in troll catches the following day.

For all the Line Islands, *Manning* trolled 285.5 h and caught 882 yellowfin tuna weighing 13.3 MT (29,319 lb). Also taken were 178 wahoo or ono weighing 217 MT (5,888 lb) and smaller numbers of skipjack tuna, rainbow runners, *Elagatis bipinnulatus*, and barracuda, *Sphyraena* sp.

Bates compared the troll catches of yellowfin tuna from Kingman Reef, Palmyra Island, and Washington Island by 2-h periods to determine whether availability of tuna varied by time of day among the
21 areas (Table 21). He concluded that tuna in these islands were caught with near-equal success throughout the day.

Bates also acquired information from a Captain Northrup Castle of Honolulu, who had fished commercially throughout the Line Islands. According to Captain Castle's account, the main body of birds on Christmas Island travel each morning in a northerly direction to an area some 370 km (200 mi) out to sea on a course line to Honolulu. According to Bates, this is the area of convergence of the Equatorial Countercurrent with a northwesterly current originating at Christmas Island (possibly the South Equatorial Current). Captain Castle stated that he saw boobies by the thousands working over a tremendous concentration of breezing yellowfin tuna. Some of the yellowfin tuna caught by Captain Castle exceeded 136 kg (300 lb).

Murphy and Ikehara (1955) also reported on the troll catches of several research vessels operating in the Line Islands. Their results showed that primary trolling in the Line Islands produced a much higher catch rate than in the Hawaiian Islands. The catch rate for tuna was
22 27.6 fish per 100 line-hours, practically all yellowfin tuna (Table 22).

The results of nine fishing cruises to the Line Islands by POFI research vessels from March 1955 to February 1956 were discussed by Iversen and Yoshida (1957). On these cruises, where both trolling and longlining were attempted, the troll catch amounted to 2,397 fish, 980 (41%) of which were yellowfin tuna. The remainder was made up of skipjack tuna (2%), wahoo (48%), and miscellaneous fish including rainbow runner, jack, dolphin, barracuda, red snapper, little tunny, needlefish, leatherjacket, and sharks (9%).

Detailed examination of trolling results led Iversen and Yoshida (1957) to conclude that yellowfin tuna catch rates in the Line Islands peaked in March-April (1.3 to 7.3 fish per hour) for all islands and were generally low the rest of the year (Fig. 52). They found that slightly higher catch rates occurred in the morning on some of the cruises (Fig. 53) and that yellowfin tuna were generally more abundant at Palmyra and Kingman Reef than at Christmas Island (Fig. 54). Bates (1950) also reported similar results.

Iversen and Yoshida (1957) compared their results with those obtained by Bates (1950) and Murphy and Ikehara (1955) and the data are given in Table 23. Of significance was the high catch rate of 3.1 fish per hour obtained in April-June 1950 and the low catch rates of 1.4 and 1.2 fish per hour calculated for the other two periods. They concluded that the abundance of yellowfin tuna in the Line Islands during the survey period was too low to encourage commercial exploitation by trolling vessels. Furthermore, there appeared to be a seasonal change in abundance, with catch rates in March-April usually higher than at other times of the year.

Species commonly taken in the Line Islands are given in Table 24. Murphy and Shomura (1972) listed 18 species of fish caught by longline but also included those likely to be captured by trolling or be seen at the surface in the central equatorial Pacific. Helfrich (1973) modified this list by adding rainbow runner and crevalles.

Longline Fishing

Despite consistent evidence of chemical enrichment of the surface layer at the equator through upwelling accompanied by a greater concentration of zooplankton in the vicinity of the equator than in adjacent latitudes, extensive surface fishing trials proved disappointing. Exploratory pole-and-line fishing with live bait, purse seining, and trolling produced little or no tuna in the zonal band of enrichment. There was, however, some good fishing in the immediate vicinity of some of the atolls in the Line Islands. The only method of fishing that proved satisfactory for sampling the large, pelagic, subsurface tunas was the longline, which can be fished at depths ranging from 30 to 133 m (100 to 400 ft).

The early longline fishing cruises to the central equatorial Pacific proved that there was indeed a concentration of deep-swimming yellowfin tuna which appeared to be associated with increased food supply from upwelled nutrient-rich water (Murphy and Shomura 1952, 1953a). The number of fish caught on these and subsequent cruises is given in Table 25. Figure 55 illustrates the catch rates of yellowfin and other tunas between lat. 5°S and 15°N and between long. 150° and 170°W.

After the initial longline fishing survey, Murphy and Shomura suggested that the equatorial stocks of deep-swimming tunas appeared capable of supporting an American fishery. Based on a catch rate of 12.3 yellowfin tuna per 100 hooks in the survey area as opposed to 3 tuna per 100 hooks in the western Pacific, they concluded that there was a greater concentration of tuna in the central than in the western equatorial Pacific.

Catches made on subsequent longline cruises in 1952 gave evidence that the "rich zone" of yellowfin tuna in the equatorial region varied latitudinally and that this zone generally coincided with differences in the prevailing wind (Murphy and Shomura 1953b, 1972). During periods of northeast trades, yellowfin tuna was most abundant south of the equator; during southeast trades, north of the equator (Fig. 44). Peak abundance straddled the equator during variable winds.

High catches of albacore in southern latitudes on long. 169°W and 180° pointed to the possibility of commercial exploitation for this species (Murphy and Shomura 1953b). The results of experimental fishing also showed that gear with longer float lines, fishing at a deeper level, was more efficient in catching albacore.

The longitudinal variation in catch rates of yellowfin tuna and albacore was also investigated by Murphy and Shomura (1955). The results of four longline cruises in 1952 to the central equatorial Pacific between long. 120° and 170°W showed that at long. 120°W, where upwelling was very intense, yellowfin tuna catches were usually low. This condition suggested that the water had not been in the photosynthetic zone long enough to have developed a favorable food supply. Murphy and Shomura (1972) showed that the presence of colder water was associated with more phosphate, more zooplankton, and fewer yellowfin tuna (Fig. 56). There were less phosphate, less zooplankton, and more yellowfin tuna associated with warmer waters. These differences reflected the time lapse after enrichment through upwelling. Variations at a geographical locality were believed to be in response to variations in wind flow that affected the rate of upwelling.

Six longline cruises in 1953 provided data that were consistent with earlier findings. Yellowfin tuna abundance continued to be centered in the region near the equator enriched by upwelling (Shomura and Murphy 1955). Furthermore, it became obvious also that the centers of abundance of bigeye tuna and albacore were away from that of yellowfin tuna (Fig. 57). Bigeye tuna were most abundant in the region of the countercurrent and albacore most abundant south of the equator (Murphy and Shomura 1972). In terms of vertical distribution, Shomura and Murphy (1955) discovered that yellowfin tuna were taken more frequently on the deeper fishing hooks. Catches of bigeye tuna and albacore also showed this tendency, and to an even greater degree.

In 1952, after 2 years of study of the tuna resources around the Line Islands, POFI chartered a west coast purse seiner, Cavalieri, to fish on a semi-commercial basis with longline gear (McKernan 1953; Sette and staff 1954). Thirty-three days of fishing produced 41.4 MT (91,255 lb) of yellowfin and bigeye tunas. The Cavalieri's catch rate of 5.2 tuna per 100 hooks was twice as good as the average for Japanese vessels fishing in grounds west of 180°, although somewhat below the average catch rate of 6.3 tuna per 100 hooks for POFI research vessels. The venture proved that west coast fishing vessels of the Cavalieri type could be readily adapted to fish longline gear.

Not all the fish unloaded by the Cavalieri could be canned. McKernan (1953) reported that of the 41.4 MT (91,255 lb) of yellowfin and bigeye tunas delivered to the cannery, 12.6 MT (27,750 lb) were rejected because of "off-color." Rejected were 3.8 MT (8,500 lb) of bigeye tuna and 8.6 MT (19,000 lb) of yellowfin tuna. Figure 58 shows, by size, the percentage acceptance of yellowfin and bigeye tunas by the cannery.

The first full-scale commercial attempt by American fishermen to fish with longline in the central equatorial Pacific began in 1954. The North American and Alrita, working under a contract whereby they were paid by the government only to offset costs for gear and deck arrangements not normally used by these vessels, each made two trips fishing with longline (Iversen and Murphy 1955; Iversen and Yoshida 1956). In 121 fishing days, they landed four full cargoes of fish. On the first set of cruises, each of the vessels averaged 1.59 MT (1.75 ST) of yellowfin tuna per day fished and on the second set about 1.61 MT (1.78 ST). These vessels found better fishing within 110 km (60 mi) of Christmas Island than at greater distances. Based on these results, Iversen and Murphy (1955) concluded that it was commercially practical for American fishing vessels with relatively small crews to fish for yellowfin tuna with longline in the central equatorial Pacific.

Encouraged by the North American's and Alrita's results, four other vessels: Brothers, Oceanic, Sea Hawk, and Commonwealth, attempted commercial fishing in the Line Islands area in 1954. Iversen and Yoshida (1956) analyzed the longline catch data collected not only by the American commercial fishing vessels but also by research vessels operating in the central equatorial Pacific. For the Line Islands area, they found a seasonal trend in yellowfin tuna catch rates, which were high in February and very low in July-August and again in October. In November, the catch rates increased slightly over those for the summer months but remained considerably lower than those of the early part of the year. Iversen and Yoshida found that the catch rates of Japanese longline vessels based at Pago Pago, American Samoa, showed a similar pattern. The results also showed that yellowfin tuna catch rates did not vary significantly among different localities close to the Line Islands. This indicated a random distribution of fish with respect to each individual island.

In an attempt to increase the efficiency of fishing with longline gear, a mainline of wire rope rather than the standard cotton was used on the cruises of the Brothers, Oceanic, and Commonwealth (Iversen and Yoshida 1956). Steel mainline had an advantage in that it could be spooled onto one large reel or drum whereas cotton mainline, joined in sections called baskets needed to be run through a longline hauler to be coiled before being placed in individual baskets (see Murphy and Shomura (1953a) for detailed description of the gear). Comparison showed that steel gear had a lower catch rate than fabric gear. The vessels experimenting with steel gear had difficulty with the steel mainline and lost many tuna, owing primarily to the lack of drag in the water and stretch in the mainline (U.S. Fish and Wildlife Service 1955). A test of both cotton and steel gear on a research vessel showed that although both gear caught about the same number of yellowfin tuna, the catch by steel gear consisted of fewer medium and large yellowfin tuna. Lack of resiliency in steel gear permitted a higher proportion of large tunas to struggle free of the hooks.

Other results reported by Iversen and Yoshida (1956) diverged sharply from previous observations. Shomura and Murphy (1955) found that the highest catches in the Line Islands area occurred in July-September in 1951-53, whereas Iversen and Yoshida reported that in 1954 the highest catches occurred in February. This discrepancy in the seasonal trend of catch, according to Iversen and Yoshida, is good evidence of a change in the abundance or distribution of yellowfin tuna, possibly related to a change in the environment.

Yellowfin tuna catches in the Line Islands are positively correlated with sea temperatures. But Tester (1956) pointed out that temperature change was not the direct cause of changes in tuna abundance. Rather, surface temperature was an indicator of the age of the water subsequent to upwelling, the coolest water being considered newly upwelled and warmer water as having been longer at the surface for tuna forage to develop in it.

Yellowfin tuna catch rates and sea-surface temperature
59 obtained at Christmas Island in 1954 showed similar trends (Fig. 59). Both were relatively high early in the year and relatively low in late summer and fall.

60 Figure 60 shows the longline catch rates calculated for March 1955 to February 1956 (Iversen and Yoshida 1957). In general, catch rates at insular stations (less than 18 km or 10 mi from land) were higher than those of oceanic stations, which were consistently low during the survey period. Insular catch rates showed considerable variation throughout the year and two possible causes were fishing at different seasons and fishing in different areas.

SIZE OF FISH

In the Line Islands region, surface yellowfin tuna caught by
1 pole-and-line and live bait were usually small as seen in Figure 61. Murphy and Shomura (1972) reported that the average size of yellowfin tuna caught by this gear was about 13 kg (29 lb). Similarly, Ikehara

(1953) reported that most of the yellowfin tuna caught by pole-and-line weighed between 9 and 14 kg (20 and 30 lb). Ikehara also discovered that these small, "one-pole" fish often took the hook first when chumming began, but were soon displaced by large deep-swimming yellowfin tuna which required as many as six poles for one hook. He noted that this type of mixed-size schools occurred commonly in the Line Islands usually close to land. Non-uniformity in size of the yellowfin tuna made fishing difficult and hazardous; it often slowed fishing so that poor catches were made from good-biting schools.

62 Concerning troll-caught fish, Figures 61 and 62 show the sizes of yellowfin tuna caught in the Line Islands. Murphy and Shomura (1972) gave the average size of troll-caught yellowfin tuna as 15 kg (33 lb). Bates (1950) showed that yellowfin tuna taken in a trolling survey in 1950 varied from 4 to 75 kg (8 to 165 lb) and averaged slightly over 15 kg (34 lb). Furthermore he noted that some lost fish were as large as 91 kg (200 lb). Overall, the size distribution of troll-caught yellowfin tuna from the Line Islands showed a pronounced mode between 7 and 8 kg
ote 7 (15 and 18 lb) and another between 26 and 29 kg (57 and 65 lb).[7] The size distribution of yellowfin tuna caught by trolling in a 1955-56 survey and reported by Iversen and Yoshida (1957), showed only a single mode that fell between 6 and 10 kg (14 and 21 lb) with a range of 2 to
63 67 kg (5 to 148 lb) (Fig. 63).

Like troll-caught fish, longline-caught, deep-swimming yellowfin tuna also had a wide variation in size (Fig. 61). But the size ranged from 5 to 92 kg (12 to 204 lb) (Shomura and Murphy 1955). Longline-caught yellowfin tuna averaged 55 kg (122 lb), or roughly four times the average weight of yellowfin tuna taken by pole-and-line fishing and trolling.

Yellowfin tuna sizes differed not only between the surface and deeper layers but also with distance from land (Shomura and
4 Murphy 1955). Figure 64, which shows the size distribution of yellowfin tuna caught in oceanic and insular areas, illustrates that larger numbers of small yellowfin tuna were captured close to land. This fact has been substantiated by longline catches made in 1955-56. Iversen and Yoshida (1957) found that in the size distribution of oceanic yellowfin tuna, the single mode fell between 54 and 65 kg (119 and 144 lb) as seen in Figure 63. The size distribution of insular yellowfin tuna had a similar mode between 54 and 65 kg (119 and 144 lb), but it also included more small fish in relation to the large ones.

Another interesting fact about the tuna taken near the equator was the difference in size in an east-west direction across the Pacific. Examining tuna catches by longitude of capture, Murphy and Shomura (1953b, 1955) discovered that the sizes of longline-caught yellowfin and bigeye tunas in the oceanic areas increased from west to
5,66 east (Figs. 65 and 66). The explanation offered was that the growth rates of these tunas change across the Pacific, reflecting the relative

availability of food. Murphy and Shomura found this proposal compatible with estimates of upwelling. Whereas along the equator in the western Pacific between long 140° and 170°E there is no evidence of upwelling (Murphy and Otsu 1954), there is moderate to strong upwelling in the central Pacific between long. 180° and 150°W (Cromwell 1953; Murphy and Shomura 1953a, 1953b, 1955; Austin 1954a). And in the eastern Pacific between long. 145° and 120°W, upwelling appears to be very intense at various times of the year.

Size distribution of longline-caught albacore and bigeye tuna may be found in Figure 61 and of skipjack tuna in Figure 67. Whereas albacore caught in the central Pacific averaged 17 kg (37 lb) or only slightly larger than troll-caught yellowfin tuna, longline-caught bigeye tuna were by far the largest among the tunas taken near the equator. Murphy and Shomura (1972) gave the average size of bigeye tuna as 77 kg (170 lb). Skipjack tuna, taken only incidentally by longline gear, averaged 9 kg (20 lb).

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SURFACE CURRENTS AND TEMPERATURES

SOURCE OF INFORMATION

The information relating to monthly surface currents shown on this chart was compiled from observations made during the month for all years prior to 1935 by the co-operating observers of the Hydrographic Office. Observations were not considered reliable where tidal currents prevailed; where winds, sea, or swell of force 6 or above were recorded; where the vessel's draft or trim would cause excessive leeway; or when doubt existed as to the meaning of the entry "Nil" on the current report. All current calculations are based on the MEDIAN POSITION method; namely, each observation is applied at only one point, that point being midway between the beginning and end of the ship's run for which the current observation was made.

RESULTANT CURRENTS

The black arrows and numerals show the mean direction and force of the surface current in each 1-degree quadrangle for the month under average normal conditions. The accuracy of the resultant current in any quadrangle is necessarily determined by the number of observations used in the computation. The Hydrographic Office considers a resultant to be fairly accurate if computed from five or more observations in an area of 3,600 square miles. But on this chart all reliable information is shown, for the benefit of the navigator, even where less than the desired five observations were obtained.

The resultant currents in each 1-degree quadrangle are shown as follows:

The number in the upper right hand corner of the quadrangle represents the total current observations used in the computation. The numerals in the lower left hand corner of the quadrangle give the resultant drift in miles per day to the nearest tenth of a mile. The direction of the arrow in the center of the quadrangle shows the resultant set.

PREVAILING CURRENTS

The current roses ~~shown in green on this chart~~ were computed from the same information as the 1-degree resultants shown in black. The eight-point rose presents a graphical picture of the frequency of direction and the average drifts within the directions for each area outlined by the heavy brown lines.

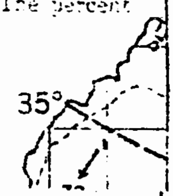
The arrows point in the direction towards which the current sets. When the frequency of direction is less than 5 percent, no arrow is shown. The length of the arrow, from the base of the arrow head to the inner edge of the circle, when placed on the attached frequency scale gives the number of times in each 100 observations that the current has been setting in or near the indicated direction. In instances where the full length of the arrow cannot be shown, the shaft is broken and the true percentage inserted in numerals within the break. The width of the shaft when placed on the attached drift scale gives the average drift in knots. The numeral in the center circle gives the percent of "nils" (no appreciable current observed). The approximate number of observations from which the current rose was computed can be obtained by adding the number of observations within the 1-degree quadrangles covered by the rose.

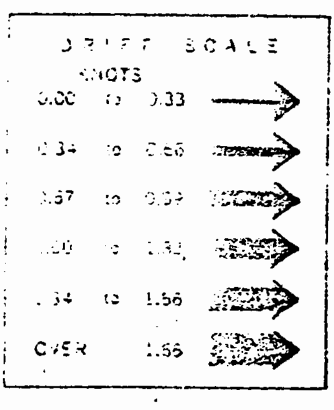
For example the attached rose should be read as follows:

Of the currents observed; 5 percent were setting northeast, the average drift was between 0.33 and 0.66 of a knot; 5 percent were setting east, the average drift was between 0.33 and 0.66 of a knot; 9 percent were setting southeast, the average drift was less than 0.33 of a knot; 5 percent were setting south, the average drift was between 1.33 and 1.66 knots. 57 percent were setting west, the average drift was between 0.67 and 1 knot; 5 percent were setting northwest, the average drift was less than 0.33 of a knot. The percent of "nils" was zero.

SEA TEMPERATURES

The monthly mean sea surface 5-degree isotherms ~~shown in MAGENTA~~ were compiled from the same source and for the same period as the resultant currents shown on this chart.





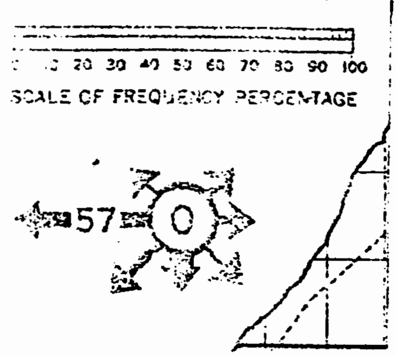


Table 1.--Minimum time and fetch required for winds to produce waves of a given height, and length of the resulting waves (adapted from McGary and Naito 1957 by BCF 1963).

TO PRODUCE WAVES	WIND VELOCITY 20 KNOTS			25 KNOTS			30 KNOTS			35 KNOTS			40 KNOTS		
	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)	TIME (HOURS)	FETCH (NAUT. MILES)	LENGTH (FEET)
4 FEET HIGH	3.2	11	40	2.0	7	43	1.3	<5	46	1.0	<5	49	0.9	<5	50
8 FEET HIGH	19.0	120	155	6.2	26	86	4.0	18	82	3.0	14	86	2.2	11	86
12 FEET HIGH				20.0	745	216	8.0	48	133	5.4	31	123	4.0	22	125
16 FEET HIGH							16.2	125	237	8.9	59	172	6.3	42	166
20 FEET HIGH										14.0	120	258	9.1	67	216
24 FEET HIGH										31.0	320	462	13.4	115	238
28 FEET HIGH													20.9	210	406
32 FEET HIGH													36.5	440	620

Table 2.-- Surface wind summaries for years with extreme rainfall at Malden Island (from Seelye 1950).

Year commencing	Rainfall	Percentage wind frequency								
		N	NE	E	SE	S	SW	W	NW	Calm
	Inch									
May 1914	100.30	11	17	38	11	1	1	3	6	12
April 1924	6.84	0	7	88	4	0	0	0	0	1

Table 3.--The average annual rainfall, its variability, and the percentage frequency of dry months at Fanning and Malden Islands (from Seelye 1950).

Island	Annual rainfall		Percentage frequency of dry months				
	Average	Variability	Summer	Autumn	Winter	Spring	Year
	Inches	Percent	Percent	Percent	Percent	Percent	Percent
Fanning	84	41	46	15	15	45	30
Malden	28	67	68	39	42	58	52

Table 4.--Mean, highest and lowest monthly and annual rainfall for the period 1903-66 at London, Christmas Island, in millimeters (from Jenkin and Foale 1968).

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mean 23 years	72	80	118	163	86	75	74	32	32	18	21	42	813
Mean 33 years	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	873
Highest monthly	575	671	482	539	291	283	199	164	203	98	117	347	2 621*
Lowest monthly	0	1	0	8	1	0	0	1	0	0	0	0	177**

* highest annual rainfall, 1941 ** lowest annual rainfall, 1954 n.a. = not available

Table 5.--Summary of monthly temperature data for London, Christmas Island 1953-65 in °C and °F (from Jenkin and Foale 1968).

Data	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Temperatures	°C												
Mean monthly 0800 h	26.6	26.7	27.0	27.2	28.0	27.5	27.5	27.0	27.6	27.7	27.3	26.8	27.2
Mean monthly 1400 h	29.4	29.3	30.1	29.7	30.6	30.2	30.1	29.6	30.3	30.3	30.1	29.4	29.9
Mean monthly 2000 h	25.9	25.9	26.1	26.1	27.0	26.5	26.5	25.9	26.3	26.2	26.0	25.7	26.1
Mean monthly maximum	30.0	30.0	30.4	30.3	30.7	30.6	30.3	30.5	30.4	30.4	30.5	30.0	30.3
Mean monthly minimum	24.4	24.3	24.7	24.9	25.0	24.8	24.6	24.8	24.6	24.5	24.4	24.3	24.6
Highest monthly maximum	33.3	32.3	32.8	33.3	33.3	33.3	32.8	33.3	33.3	33.3	35.0	36.7	36.7
Lowest monthly minimum	21.8	21.8	21.7	21.1	21.7	20.8	21.3	22.1	22.8	22.2	21.1	21.1	20.8
Mean monthly*	27.2	27.2	27.5	27.6	27.8	27.7	27.4	27.7	27.5	27.5	27.4	27.1	27.4
Temperatures	°F												
Mean monthly 0800 h	79.9	80.0	80.6	81.0	82.4	81.5	81.5	80.6	81.7	81.9	81.1	80.2	81.0
Mean monthly 1400 h	85.0	84.7	86.2	85.5	87.1	86.3	86.2	85.2	86.6	86.5	86.1	85.0	85.9
Mean monthly 2000 h	78.6	78.7	78.9	79.0	80.6	79.7	79.7	78.7	79.3	79.1	78.8	78.2	79.1
Mean monthly maximum	86.1	86.0	86.7	86.5	87.2	87.1	86.6	86.8	86.7	87.0	86.6	86.0	86.6
Mean monthly minimum	75.9	75.8	76.4	76.7	77.1	76.6	76.3	76.7	76.3	76.0	76.0	75.7	76.3
Highest monthly maximum	92.0	90.0	91.0	92.0	92.0	92.0	91.0	92.0	92.0	92.0	95.0	98.0	98.0
Lowest monthly minimum	70.0	71.2	71.0	70.0	71.0	69.4	70.3	71.1	73.0	71.9	70.0	70.0	69.4
Mean monthly*	81.0	80.9	81.5	81.7	82.1	81.9	81.4	81.8	81.5	81.5	81.3	80.8	81.5

* ½ (mean monthly maximum + mean monthly minimum)

Table 6.--Average mean monthly and annual atmospheric pressure at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in millibars (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
0800	1010.0	1010.0	1010.2	1009.7	1009.8	1010.2	1010.2	1010.1	1010.4	1010.7	1010.4	1010.2	1010.2
1400	1007.4	1007.4	1008.1	1007.7	1008.0	1008.4	1008.7	1008.4	1008.3	1008.1	1007.5	1007.3	1007.9
2000	1008.9	1008.7	1009.2	1008.7	1009.0	1009.5	1009.4	1009.3	1009.6	1009.7	1009.3	1008.9	1009.2

Table 7.--Average mean monthly and annual relative humidity at 0800, 1400, and 2000 h (local time) and for the whole day at London, Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
0800	77.3	78.4	79.8	80.4	76.5	75.4	76.2	73.8	71.3	70.5	71.4	74.8	75.5
1400	62.0	63.4	65.1	68.2	64.1	62.7	63.1	59.2	59.3	58.8	58.5	61.0	62.1
2000	81.3	81.7	83.9	84.4	80.8	79.9	78.9	77.6	77.6	77.3	77.6	79.1	80.0
Day*	71.7	74.7	74.6	73.6	72.5	71.2	71.2	68.5	68.5	68.0	68.0	70.2	71.1

* ½ (mean monthly relative humidity at 1400 h + mean monthly relative humidity at 2000 h)

Table 8.--Average mean monthly and annual cloud cover at 0800, 1400, and 2000 h (local time) at London, Christmas Island, 1953-65, in oktas and tenths (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	Oktas												
0800	3.8	3.8	4.2	4.5	3.7	3.6	3.7	3.4	3.4	3.5	3.8	3.8	3.8
1400	4.1	4.1	4.3	4.7	4.0	3.9	4.1	3.7	3.5	3.9	3.8	4.2	4.0
2000	3.0	3.0	3.3	3.6	2.9	2.9	2.9	2.7	2.6	2.8	2.6	2.9	2.9
	Tenths												
0800	4.8	4.7	5.2	5.6	4.6	4.5	4.6	4.3	4.3	4.4	4.8	4.7	4.7
1400	5.2	5.1	5.4	5.9	5.0	4.9	5.1	4.6	4.4	4.9	4.8	5.3	5.1
2000	3.7	3.8	4.2	4.5	3.6	3.6	3.6	3.4	3.3	3.5	3.3	3.6	3.7

Table 9.--Mean monthly sunshine in hours per day at London, Christmas Island (from Jenkin and Foale 1968).

Year	J	F	M	A	M	J	J	A	S	O	N	D
1953	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	n. a.	8.3
1954	8.5	8.4	8.4	7.9	n. a.	8.4	8.3	8.7	8.9	8.7	8.2	8.3
1955	7.9	8.4	8.0	8.2	8.5	8.5	8.3	8.9	8.8	8.4	8.0	8.2
1956	8.8	9.1	8.0	8.2	9.4	9.0	9.6	9.7	9.1	9.4	9.2	9.5
1957	9.5	9.5	9.7	9.0	9.0	9.1	8.7	10.0	9.5	9.7	9.0	8.3
1958	8.3	9.0	9.2	9.0	8.9	9.6	9.5	9.5	10.0	9.8	9.7	9.5
1959	9.8	9.2	9.5	8.9	9.7	9.3	9.3	10.0	9.9	9.8	10.1	10.3
1960	10.3	10.1	10.3	9.8	10.3	10.3	10.4	10.6	10.7	11.1	10.6	11.0
1961	10.7	10.6	10.7	10.4	10.5	10.5	n. a.	10.9	n. a.	n. a.	10.8	n. a.
1962	n. a.	n. a.	n. a.	n. a	n. a.	n. a.	10.1	n. a.	10.6	n. a.	n. a.	n. a.
1963	n. a.	n. a.	10.1	8.9	9.9	9.7	9.1	9.0	9.6	9.0	8.7	8.7
1964	8.5	8.8	8.6	8.9	8.9	9.6	9.5	9.6	9.8	9.6	9.6	9.6
1965	9.9	10.2	9.4	9.8	9.6	9.4	9.5	9.2	10.0	9.9	n. a.	n. a.
Average	9.2	9.3	9.3	9.0	9.5	9.4	9.3	9.6	9.7	9.5	9.4	9.2

Table 10.--Mean monthly and annual wind speed at 0800, 1400, and 2000 h (local time) and for the whole day in meters per second (m/s) and knots (kn) at Christmas Island, 1953-65 (from Jenkin and Foale 1968).

Local time, h	J	F	M	A	M	J	J	A	S	O	N	D	Annual
						m/s							
0800	4.4	4.1	4.0	3.7	3.7	3.6	4.0	4.5	4.3	4.2	4.5	4.4	4.1
1400	5.3	4.9	4.8	4.4	4.3	4.4	4.7	4.9	4.6	4.5	4.8	4.8	4.7
2000	4.6	4.2	3.9	3.5	3.7	3.6	3.9	4.4	4.3	4.3	4.4	4.6	4.1
Day *	4.9	4.5	4.3	4.0	4.0	4.0	4.3	4.7	4.5	4.4	4.6	4.7	4.4
						kn							
0800	8.5	8.0	7.7	7.1	7.2	7.0	7.7	8.7	8.4	8.2	8.7	8.5	8.0
1400	10.2	9.6	9.3	8.5	8.4	8.6	9.1	9.6	9.0	8.8	9.3	9.3	9.1
2000	8.9	8.1	7.5	6.8	7.1	7.0	7.5	8.5	8.4	8.4	8.5	8.9	8.0
Day *	9.6	8.8	8.4	7.7	7.8	7.8	8.3	9.1	8.7	8.6	9.0	9.1	8.6

* ½ (mean monthly wind speed at 1400 h + mean monthly wind speed at 2000 h)

Table 11.--Average volumes and night-day ratios of zooplankton collected by Clarke-Bumpus samplers on Hugh M. Smith cruise 16 for three depths of sampling, July-August 1952 (from Hida and King 1955).

Depth	Time of hauling	No. of samples	Avg. volume, $cc/1000m^3$	Ratio, N/D
Surface	Night	11	85.2	1.63
	Day	13	52.3	
Intermediate	Night	7	27.6	.90
	Day	9	30.7	
Deep	Night	6	12.5	.66
	Day	9	19.0	

Table 12.--Summary of island observations on fish schools and bird flocks, 1950-53 (from Murphy and Ikehara 1955).

Locality	Period	Number of days		Yellowfin		Skipjack		Mixed[1/]		Unidentified		Total fish schools		Bird flocks	
		Fishing and scouting	Running	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day	Number	Number per day
Line Is.	Mar.-May	26	6	16	0.5	0	0.0	2	0.1	15	0.5	33	1.0	33	1.0
	June-Aug.	4	3	13	1.9	1	0.1	4	0.6	3	0.4	21	3.0	27	3.9
	Sept.-Nov.	22	11	20	0.6	12	0.4	4	0.1	55	1.7	91	2.8	108	3.3
	Dec.-Feb.	8	19	7	0.3	4	0.1	3	0.1	24	0.9	38	1.4	71	2.6
Total and average[2/]		60	39	56	0.8	17	0.2	13	0.2	97	0.9	183	2.1	239	2.7
Phoenix Is.	Mar.-May	-	3	0	0.0	0	0.0	0	0.0	2	0.7	2	0.7	6	2.0
	June-Aug.	3	4	8	1.1	6	0.9	0	0.0	5	0.7	19	2.7	26	3.7
	Sept.-Nov.	0	2	3	1.5	2	1.0	0	0.0	2	1.0	7	3.5	1	0.5
	Dec.-Feb.	3	14	3	0.2	1	0.1	0	0.0	5	0.3	9	0.5	13	0.8
Total and average[2/]		6	23	14	0.7	9	0.5	0	0.0	14	0.7	37	1.9	46	1.8
Hawaiian Is.	Mar.-May	0	9	0	0.0	7	0.8	0	0.0	7	0.8	14	1.6	18	2.0
	June-Aug.	33	15	4	0.1	81	1.7	0	0.0	20	0.4	105	2.2	100	2.1
	Sept.-Nov.	4	31	0	0.0	17	0.5	0	0.0	21	0.6	38	1.1	47	1.3
	Dec.-Feb.	0	4	1	0.2	1	0.2	0	0.0	1	0.2	3	0.8	3	0.8
Total and average[2/]		37	59	5	0.1	106	0.8	0	0.0	49	0.5	160	1.4	168	1.6
Leeward Is.	Mar.-May	1	4	1	0.2	3	0.6	0	0.0	25	5.0	29	5.8	47	9.4
Jarvis I.	June-Aug.	1	0	2	2.0	0	0.0	0	0.0	1	1.0	3	3.0	4	4.0
	Dec.-Feb.	1	1	0	0.0	0	0.0	0	0.0	3	1.5	3	1.5	4	2.0
Malden I.	Sept.-Nov.	1	0	0	0.0	2	2.0	0	0.0	4	4.0	6	6.0	6	6.0
Starbuck I.	Dec.-Feb.	1	0	0	0.0	3	3.0	0	0.0	0	0.0	3	3.0	3	3.0
Johnston I.	Mar.-May	0	2	0	0.0	0	0.0	0	0.0	5	2.5	5	2.5	8	4.0
Marquesas Is.	June-Aug.	0	2	0	0.0	2	1.0	0	0.0	0	0.0	2	1.0	3	1.5
Samoa Is.	Dec.-Feb.	0	1	0	0.0	2	2.0	0	0.0	7	7.0	9	9.0	9	9.0
Nukunono Is.	Dec.-Feb.	0	1	0	0.0	0	0.0	0	0.0	1	1.0	1	1.0	1	1.0

1/ Yellowfin and skipjack tunas.

2/

(from Murphy and Ikehara 1955).

Locality	Period	Number of days: Fishing and scouting	Number of days: Running	Yellowfin: Number	Yellowfin: Number per day	Skipjack: Number	Skipjack: Number per day	Unidentified: Number	Unidentified: Number per day	Total fish schools: Number	Total fish schools: Number per day	Bird flocks: Number	Bird flocks: Number per day	Number of birds [2]: Number	Number of birds [2]: Number per day
Line Is.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	1	1.0	30	30.0
	June-Aug.	0	2	0	0.0	0	0.0	0	0.0	0	0.0	1	0.5	37	18.5
	Sept.-Nov.	0	3	1	0.3	2	0.7	6[3]	2.0	9	3.0	12	4.0	162	54.0
	Dec.-Feb.	0	17	0	0.0	10	0.6	21	1.2	31	1.8	36	2.1	959	56.4
Total and average[4]		0	23	1	0.1	13	0.6	27	0.8	41	1.4	50	1.9	1188	39.7
Phoenix Is.	Mar.-May	0	4	0	0.0	1	0.2	4	1.0	5	1.2	8	2.0	310	77.5
	June-Aug.	0	2	2	1.0	3	1.5	1	0.5	6	3.0	13	6.5	615	307.5
	Sept.-Nov.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Dec.-Feb.	0	4	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2	43	10.8
Total and average[4]		0	10	2	0.3	4	0.6	5	0.5	11	1.4	22	2.9	968	131.9
Hawaiian Is.	Mar.-May	0	10	0	0.0	3	0.3	5	0.5	8	0.8	12	1.2	558	55.8
	June-Aug.	1	8	0	0.0	4	0.4	10	1.1	14	1.6	19	2.1	1212	134.7
	Sept.-Nov.	0	16	0	0.0	10	0.6	7	0.4	17	1.1	16	1.0	1283	80.2
	Dec.-Feb.	0	7	0	0.0	1	0.1	1	0.1	2	0.3	3	0.4	144	20.6
Total and average[4]		1	41	0	0.0	18	0.4	23	0.5	41	1.0	50	1.2	3197	72.8
Leeward Is.	Mar.-May	0	2	0	0.0	2	1.0	1	0.5	3	1.5	3	1.5	85	42.5
Jarvis I.	Sept.-Nov.	0	1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	35	35.0
	Dec.-Feb.	0	2	0	0.0	2	1.0	0	0.0	2	1.0	8	4.0	352	176.0
Malden I.	June-Aug.	0	1	0	0.0	1	1.0	0	0.0	1	1.0	3	3.0	94	94.0
Starbuck I.	Sept-Nov.	0	1	0	0.0	0	0.0	2	2.0	2	2.0	2	2.0	86	86.0
	Dec.-Feb.	0	5	0	0.0	2	0.4	17	3.4	19	3.8	22	4.4	1172	234.4
Johnston I.	Mar.-May	0	1	0	0.0	1	1.0	0	0.0	1	1.0	2	2.0	11	11.0
Marquesas Is.	Mar.-May	0	1	0	0.0	0	0.0	0	0.0	0	0.0	1	1.0	16	16.0
	June-Aug.	0	4	0	0.0	1	0.2	3	0.8	4	1.0	5	1.2	309	77.2
Samoa - Nukunono Is.	Dec.-Feb.	0	3	0	0.0	0	0.0	2	0.7	2	0.7	2	0.7	12	4.0

1/ Semioceanic observations were considered to be from 60 to 180 miles from the islands.

2/ Includes scattered birds.

3/ Two schools of little tunny.

Table 14.--Total scouting hours and rate of sighting of bird flocks, skipjack tuna schools, and total schools in the 5° square bounded by lat. 0° and 5°N and by long. 155° and 160°W (data extracted from Naughton, see footnote 5).

Month	Total scouting hours		Sightings per 10 h of scouting: Bird flocks		Skipjack tuna schools		Total schools	
	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72	1950-61	1950-72
December-February	402	553	2.96	2.84	0.32	0.30	1.37	1.62
March-May	304	560	1.91	2.45	0.26	0.30	0.59	1.70
June-August	104	150	3.27	6.47	0.00	1.13	0.29	4.60
September-November	619	412	2.92	5.63	0.53	0.97	1.52	3.32

Note: The total scouting hours in September-November 1950-61 are higher than in 1950-72 because of adjustments made by Naughton eliminating some of the hours of darkness when no scouting was conducted.

Table 15.--Results of baiting operations in the Line Islands (data extracted from Table 1, Ikehara 1953).

Locality	Date	Number of days[1]	Number of sets		Catch (by buckets)		Species of bait	
			Beach seine	Night lift net	Beach seine	Night lift net	Beach seine	Night lift net
Line Islands:								
Palmyra Island	June 1951; August 1950	2	5	1	115	0	100% mullet	--
Christmas Island	June 1951	1	5	0	52	--	100% mullet	--
Kingman Reef	August 1950	1	0	1	--	0	--	--
Fanning Island	June 1951	1	0	0	--	--	--	--

[1]This includes only days or nights when bait fishing and/or scouting was carried on.

Table 16.--Summary of baiting operations in the Line Islands, 1955-64.

Date	Cruise	Locality	Species	Size	Sets	Catch	Catch/set
				Cm	No.	Bucket	Bucket
Jan. 31-Feb. 13, 1955	CHG-19	Palmyra, Fanning, and Christmas	Mullet, *Mugil longimanus*	--	16	106	6.6
Jan. 7, 1958	CHG-42	English Harbor at Fanning	Mostly mullet; some goatfish and milkfish	7.6-20.3	7	66	9.4
Nov. 11, 1958	CHG-42	Palmyra	Mostly mullet; some goatfish and milkfish	7.6-20.3	7	133	19.0
Oct. 21, 1960	CHG-50	Strawn Island on Palmyra	Mullet	5.1-20.3	6	33	5.5
Oct. 25, 1960	CHG-50	English Harbor at Fanning	Mostly mullet; some goatfish and milkfish	5.1-20.3	5	55	11.0
Aug. 10, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	2	2.0
Aug. 11, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	2	2.0
Aug. 11, 1962	CHG-59	Strawn Island on Palmyra	Mullet	5.1-10.2	1	8	8.0
Oct. 17, 1964	CHG-76	Christmas	Mullet, goatfish, and mountain bass	7.6-15.2	3	50	16.7
Oct. 21, 1964	CHG-76	Palmyra	Mullet	5.1-10.2	2	48	24.0

Table 17.--Summary of bait survey, <u>Charles H. Gilbert</u> cruise 19.

Date 1955	Locality	Shoreline scouted (miles)	Number of buckets	
			Seen	Caught
Jan. 31	Strawn Island - Palmyra	0.4	5	0*
Jan. 31	Paradise Island - Palmyra	0.5	10	0*
Feb. 1	Along causeway and north shore of east lagoon - Palmyra	0.5	10	0*
Feb. 1	Strawn Island - Palmyra	0.2	3	3
Feb. 1	Kaula Island - Palmyra	0.1	50	30
Feb. 4	South of English Harbor - Fanning	0.9	2	0*
Feb. 4	North of English Harbor - Fanning	1.1	50	7
Feb. 5	700 yds. northwest of Cartwright Point - Fanning	0.4	50	24
Feb. 6	700 yds. northwest of Cartwright Point - Fanning	0.2	20	20
Feb. 7	Lagoon shore northeast side Tehenua Tepapa - Fanning	2.3	50	0*
Feb. 9	Cook Island southward - Christmas	4.5	5	5
Feb. 13	Paradise Island - Palmyra	0.3	40	17

*Did not attempt to catch.

Table 18.--Summary of the results of live-bait fishing for tunas in the Line Islands (data extracted from Table 2, Ikehara 1953).

Locality	Date	Number of hours fishing and scouting		Number of fish schools seen	Number of fish schools chummed	Number of tuna schools fished	Actual time spent fishing		Number of tuna caught	Total weight of tuna caught	Number of times sharks interfered
		H	Min				H	Min		Tons	
Line Islands											
Kingman Reef	Aug. 1950	11	20	3	3	1	0	13	13	0.13	1
Kingman Reef	May 1951	17	00	15	13	6	2	05	1,008	11.75	3
Palmyra Island	June 1951	J3	50	6	5	2	0	05	22	0.25	1
Washington Island	June 1951	15	05	8	7	2	0	33	191	2.62	3
Fanning Island	June 1951	5	05	4	4	4	0	34	327	4.09	0
Christmas Island	June 1951	9	00	3	3	2	1	07	970	10.46	1
Jarvis Island	June 1951	3	00	3	1	1	0	27	10	0.15	1
Total		64	20	42	36	18	5	04	2,541	29.45	10

Table 19.--Daily troll catches in the Line Islands, <u>John R. Manning</u> cruise 2, 1950 (from Bates 1950).

Date		Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
			No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
Apr.	22	Kingman Reef	5	9-1/2*	20	767	1	35	0.42	16.2	3
	23	Do	5	10	79	2,665	2	70	1.58	53.3	5
	24	Do	5	8	53	1,955	7	245	1.32	48.8	2
	25	Do	5	9	59	1,666	5	175	1.31	37.0	0
	26	Do	6	1-1/2	5	136	0	0	0.56	15.1	0
May	28	Do	6	2	15	475	6	175	1.25	39.6	0
	29	Do	6	10	32	954	7	230	0.53	15.9	0
	30	Do	6	10	49	1,592	8	225	0.82	26.6	0
	31	Do	6	4-1/2	27	885	17	465	1.00	32.8	0
			[6]7	5-1/2	25	957	--	--	0.65	24.9	0
June	1	Do	7	7	6	239	8	245	0.12	4.9	0
	2	Do	7	3	3	175	0	0	0.14	8.3	0
Totals and averages			5.9	80	373	12,466	60	1,865	0.79	26.4	10

Table 19.--Continued.

Date	Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
		No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
Apr. 27	Palmyra	6	10	95	1,941	4	140	1.58	32.4	4
28	Do	6	7*	17	319	5	165	0.40	7.6	0
29	Do	6	6*	6	192	0	0	0.17	5.3	0
May 1	Do	6	4*	0	0	0	0	0	0	0
27	Do	6	9-1/2	29	995	7	162	0.51	17.5	0
28	Do	6	3-1/4	18	385	6	185	0.92	19.7	1
June 2	Do	7	3	1	15	0	0	0.05	0.7	0
3	Do	7	5-1/2	17	476	4	130	0.44	12.3	0
4	Do	7	4-1/2	10	290	4	98	0.32	9.2	0
Totals and averages		6.35	52-3/4	193	4,613	30	880	0.58	13.8	5
May 3	Washington	6	11*	42	1,680	9	400	0.64	25.5	0
4	Do	6	10-1/2	42	1,504	15	600	0.67	23.9	0
5	Do	6	10*	16	680	4	140	0.27	11.3	[7]1
24	Do	6	7-1/2	41	1,314	1	40	0.91	29.2	0
June 5	Do	7	[8]9	22	843	17	440	0.35	13.3	0
6	Do	7	10-1/4	33	1,080	16	393	0.46	15.0	0
Totals and averages		6.34	58-1/4	196	7,101	62	2,013	0.53	19.3	1

Table 19.--Continued.

Date	Area	Lines out	Trolling hours[1]	Tuna[2]		Wahoo[3]		Tuna per line-hour		Skipjack tuna[4]
		No.		No.	Lb	No.	Lb[5]	No.	Lb	No.
May 6	Fanning	6	1	3	120	0	0	0.50	20.0	0
8	Do	6	6*	2	66	0	0	0.06	1.8	0
9	Do	6	10	1	50	0	0	0.02	0.8	0
10	Do	6	5-1/2	0	0	0	0	0	0	1
11	Do	6	2-1/2	0	0	0	0	0	0	0
23	Do	6	4	0	0	0	0	0	0	0
June 7	Do	6	3-1/2	9	213	0	0	0.43	10.1	0
Totals and averages		6	32-1/2	15	449	0	0	0.08	2.3	1
May 12	Christmas	6	7-1/2	28	1,343	1	35	0.62	29.9	0
13	Do	[9]6	7-1/2	23	1,100	2	100	0.51	24.5	0
15	Do	6	11	5	237	5	206	0.08	3.6	0
16	Do	6	11*	5	239	1	45	0.08	3.6	0
17	Do	6	10-1/2	13	537	5	279	0.21	8.5	0
18	Do	6	5	9	405	3	105	0.30	13.5	0
19	Do	6	5	15	569	6	235	0.50	19.0	0
20	Do	6	4-1/2	7	260	3	125	0.26	9.6	0
Totals and averages		6	62	105	4,690	26	1,130	0.28	12.6	0

Table 19.--Continued.

[1]Includes hours trolled in circling islands on days starred (*).

[2]Yellowfin tuna, Thunnus albacares.

[3]Wahoo, Acanthocybium solandri.

[4]Skipjack tuna, Katsuwonus pelamis.

[5]Estimated weights.

[6]Seventh line added on May 31 just before noon.

[7]Little tunny or kawakawa (Euthynnus spp.).

[8]Commenced fishing after 0900 h.

[9]Seine set in morning--no trolling for 3-1/2 h.

Table 20.--Observations on five large schools of tuna sighted at Kingman Reef on *John R. Manning* cruise 2, 1950 (from Bates 1950).

Date	Species	Est. size of tuna	Est. size of school	
4/22	Yellowfin tuna	25-45 lb	at least 50 tons	Breezing,[1] travelling slowly east to west in manner similar to Central American schools.
4/23	Yellowfin and skipjack tunas	--	50-60 tons	Breezing, travelling fast, mixed school
	Yellowfin tuna	--	large	Travelled 1/4 mile ahead of boat at all times.
4/25	Skipjack tuna	1-2 lb	large	Shiners,[2] jumpers--appeared in 3 different schools during day.
5/29	Skipjack tuna	3-8 lb	very large	Breezing, some jumpers, off NW tip in 350-400 fathoms. Similar but smaller school sighted later in day.
5/30	Yellowfin tuna	15-60 lb mixed	small	Breezing, slow-moving. A second and similar school also seen on same day.

1/ *Breezing* is a term applied to a school of fish having the appearance of a wind disturbance or "tide rip" (e.g., a rippling effect).

2/ One indication of fish is observing their sides or bellies flashing or "shining" in the water as the fish turns partially over. *Shiners* can be seen at great depths and distances depending on type of fish and brightness of day.

NOTE: The behavior of tuna in the above table is as expressed by Captain Kursar as well as other west coast fishermen aboard with considerable fishing experience in Mexican and Central American waters. All comparative estimates of school sizes are also based on west coast tuna standards.

Table 21.--Number of yellowfin tuna caught by 2-h periods, *John R. Manning* cruise 2, 1950 (from Bates 1950).

Time	Kingman Reef-6 days[1]		Palmyra-3 days[1]		Washington-4 days[1]	
	No. of yellowfin tuna caught	Catch per 2-h period per day	No. of yellowfin tuna caught	Catch per 2-h period per day	No. of yellowfin tuna caught	Catch per 2-h period per day
0700-0900[2]	74	12.3	10	3.3	6	1.5
0900-1100	82	13.7	13	4.3	26	6.5
1100-1300	72	12.0	38	12.7	49	12.3
1300-1500[2]	39	6.5	32	10.7	38	9.5
1500-1700[2]	59	9.8	39	13.0	35	8.8

[1]Only data are used for full trolling days (between 0700 and 1700). Insufficient data are available for Fanning and Christmas Islands.

[2]Figures low during these hours only because fishing grounds were not reached without some scouting and were left earlier than 1700 on run to anchorage,

Table 22.--Results of trolling in island areas, 1950-53 (from Murphy and Ikehara 1955).

Species	Number caught, by locality											
	Line Islands	Phoenix Islands	Hawaiian Islands	Leeward Hawaiian Islands	Malden Island	Starbuck Island	Jarvis Island	Samoa Islands	Marquesas Islands	Nukunono Island	Johnston Island	Total
Primary trolling:												
TUNAS												
Yellowfin	241	34	-	1	7	11	29	-	-	-	-	323
Skipjack	5	0	-	0	0	0	0	-	-	-	-	5
Little tunny	0	0	-	0	0	0	0	-	-	-	-	-
Total	246	34	-	1	7	11	29	-	-	-	-	328
MISCELLANEOUS												
Dolphin	0	0	-	0	0	0	0	-	-	-	-	-
Wahoo	171	7	-	0	3	8	12	-	-	-	-	201
Jacks	11	0	-	0	1	0	0	-	-	-	-	12
Rainbow runner	8	0	-	0	0	0	0	-	-	-	-	8
Others	24	0	-	0	1	0	0	-	-	-	-	25
Total	214	7	-	0	5	8	12	-	-	-	-	246
Grand Total	460	41	-	1	12	19	41	-	-	-	-	574
Line hours	890	79	-	13	14	20	12	-	-	-	-	1,028
Tuna/100 line hours	27.6	43.0	-	7.7	50.0	55.0	241.7	-	-	-	-	31.9
All species/100 line hours	51.5	51.8	-	7.7	85.6	95.0	341.7	-	-	-	-	55.8
Secondary trolling:												
TUNAS												
Yellowfin	34	1	3	0	0	0	0	0	0	0	3	41
Skipjack	1	0	6	0	0	0	0	0	0	0	0	7
Little tunny	0	0	1	7	0	0	0	0	0	0	0	8
Total	35	1	10	7	0	0	0	0	0	0	3	56
MISCELLANEOUS												
Dolphin	0	0	11	2	0	0	0	1	0	0	0	14
Wahoo	17	3	2	1	0	0	0	0	0	0	0	23
Jacks	1	0	0	0	0	0	0	0	0	0	0	1
Rainbow runner	2	0	0	0	0	0	0	0	0	0	0	2
Others	2	0	0	0	0	0	0	0	0	0	0	2
Total	22	3	13	3	0	0	0	1	0	0	0	42
Grand total	57	4	23	10	0	0	0	1	0	0	3	98
Line hours	739	339	930	173	8	10	46	29	22	32	56	2,384
Tuna/100 line hours	4.7	0.3	1.1	4.0	0.0	0.0	0.0	0.0	0.0	0.0	5.4	2.3
All species/100 line hours	7.7	1.2	2.5	5.8	0.0	0.0	0.0	3.4	0.0	0.0	5.4	4.1

Table 23.--Results of trolling in the Line Islands (from Iversen and Yoshida 1957).

Time	Hours trolled	Yellowfin tuna	
		Number	Catch per hour
April to June 1950 (Bates 1950)	285.5	882	3.1
October 1950 to April 1953 (Murphy and Ikehara 1955)	[1]178.0	241	1.4
March 1955 to February 1956	766.5	946	1.2

[1]Murphy and Ikehara (1955) reported 890 line-hours of trolling using 4-6 lines. The number of hours trolled was obtained by dividing 890 line-hours by five, the average number of lines trolled.

Table 24.--Species of fish listed by Murphy and Shomura (1972) as likely to be captured by trolling or observed near the surface in the central equatorial Pacific Ocean (from Helfrich 1973).

Albacore, *Thunnus alalunga* (Bonnaterre)
Barracuda, *Sphyraena barracuda* (Walbaum)
Bigeye tuna, *Thunnus obesus* (Lowe)
Blue marlin, *Makaira ampla* (Poey)
Bonita shark, *Isurus glaucus* (Muller and Henle)
Broadbill swordfish, *Xiphias gladius* (Linnaeus)
Common dolphin, *Corphaena hippurus* (Linnaeus)
Great blue shark, *Prionace glauca* (Linnaeus)
Lancetfish, *Alepisaurus* sp.
Sailfish, *Istiophorus platypterus* (Shaw and Nodder)
Shortnose spearfish, *Tetrapturus angustirostris* (Tanaka)
Silky shark, *Eulamia floridanus* (Bigelow, Schroeder & Springer)
Skipjack tuna, *Katsuwonus pelamis* (Linnaeus)
Striped marlin, *Makaira audax* (Philippi)
Wahoo, *Acanthocybium solandri* (Cuvier & Valenciennes)
White marlin, *Istiompax marlina* (Jordan and Hill)
Whitetip shark, *Pterolamiops longimanus* (Poey)
Yellowfin tuna, *Thunnus albacares* (Bonnaterre)
Rainbow runner, *Elagatis bipinnulatus*
Crevalles (Jacks), *Caranx melampygus*

Table 25.--Number of tuna, marlin, shark, and other species caught on longline gear on exploratory fishing cruises to the central equatorial Pacific Ocean, 1950-56.

Vessel name	Cruise No.	Yellowfin tuna	Bigeye tuna	Albacore	Skipjack tuna	Marlin	Shark	Others
		No.	No.	No.	No.	No.	No.	No.
Hugh M. Smith	[1]5	71	--	4	--	6	55	--
	[1]7	183	22	--	5	19	94	30
	[1]11	95	23	5	10	5	31	14
	[2]18	59	50	1	14	21	170	56
	[3]19	174	1	--	1	4	78	8
John R. Manning	[4]11	211	30	64	17	20	153	19
	[2]12	144	28	2	8	11	77	34
	[2]13	148	28	21	33	19	170	34
	[3]14	294	45	40	29	45	148	40
	[3]15	277	57	101	24	24	198	35
	[3]16	466	51	31	14	28	233	50
	[3]17	149	6	4	4	8	52	5
	[3]18	171	8	2	6	6	183	28
	[5]20	425	17	7	8	13	415	17
	[6]24	128	4	--	2	9	131	9
	[6]27	158	5	--	2	3	155	9
	[6]28	21	--	--	3	1	73	8
	[6]29	169	9	--	7	9	222	9
Charles H. Gilbert	[4]1	72	43	--	--	8	64	20
	[5]15	218	78	13	18	26	409	51
	[6]20	246	1	--	3	7	182	6
	[6]25	23	1	--	5	3	37	7
Cavalieri	[2]1	720	65	--	29	18	195	105
North American	[5]1	1,440	13	13	20	13	369	31
	[5]2	1,730	8	11	77	41	513	19
Alrita	[5]1	1,338	12	14	11	9	481	4
	[5]2	689	7	9	22	16	216	3

Table 25.--Continued.

Vessel name	Cruise No.	Yellowfin tuna	Bigeye tuna	Albacore	Skipjack tuna	Marlin	Shark	Others
		No.	No.	No.	No.	No.	No.	No.
Oceanic	[5]1	59	2	--	--	4	151	1
	[5]2	104	1	--	3	--	85	2
Brothers	[5]1	117	--	--	--	4	140	--
	[5]2	36	1	--	2	1	45	1
Sea Hawk	[5]1	58	--	--	3	9	136	1
Commonwealth	[5]1	99	7	1	9	5	87	6
	[5]2	178	2	--	2	10	191	3
	[6]3	40	6	--	2	3	53	2
	[6]4	137	4	--	4	5	114	1
	[6]5	78	1	--	4	4	71	4

[1]Data are from Murphy and Shomura (1953a).

[2]Data are from Murphy and Shomura (1955).

[3]Data are from Shomura and Murphy (1955).

[4]Data are from Murphy and Shomura (1953b).

[5]Data are from Iversen and Yoshida (1956).

[6]Data are from Iversen and Yoshida (1957).

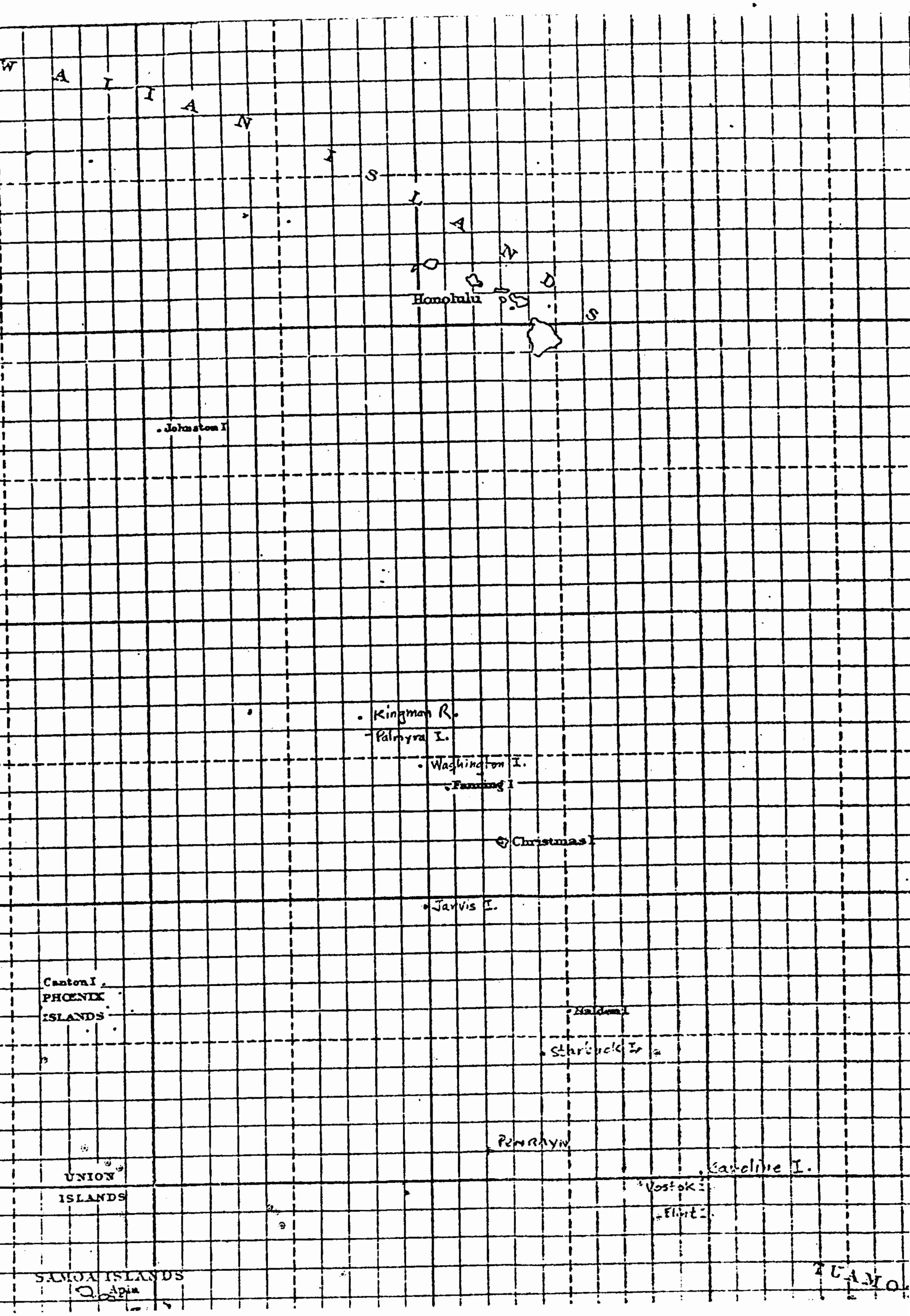


Figure 1.--The location of the Line Islands in the central equatorial Pacific Ocean.

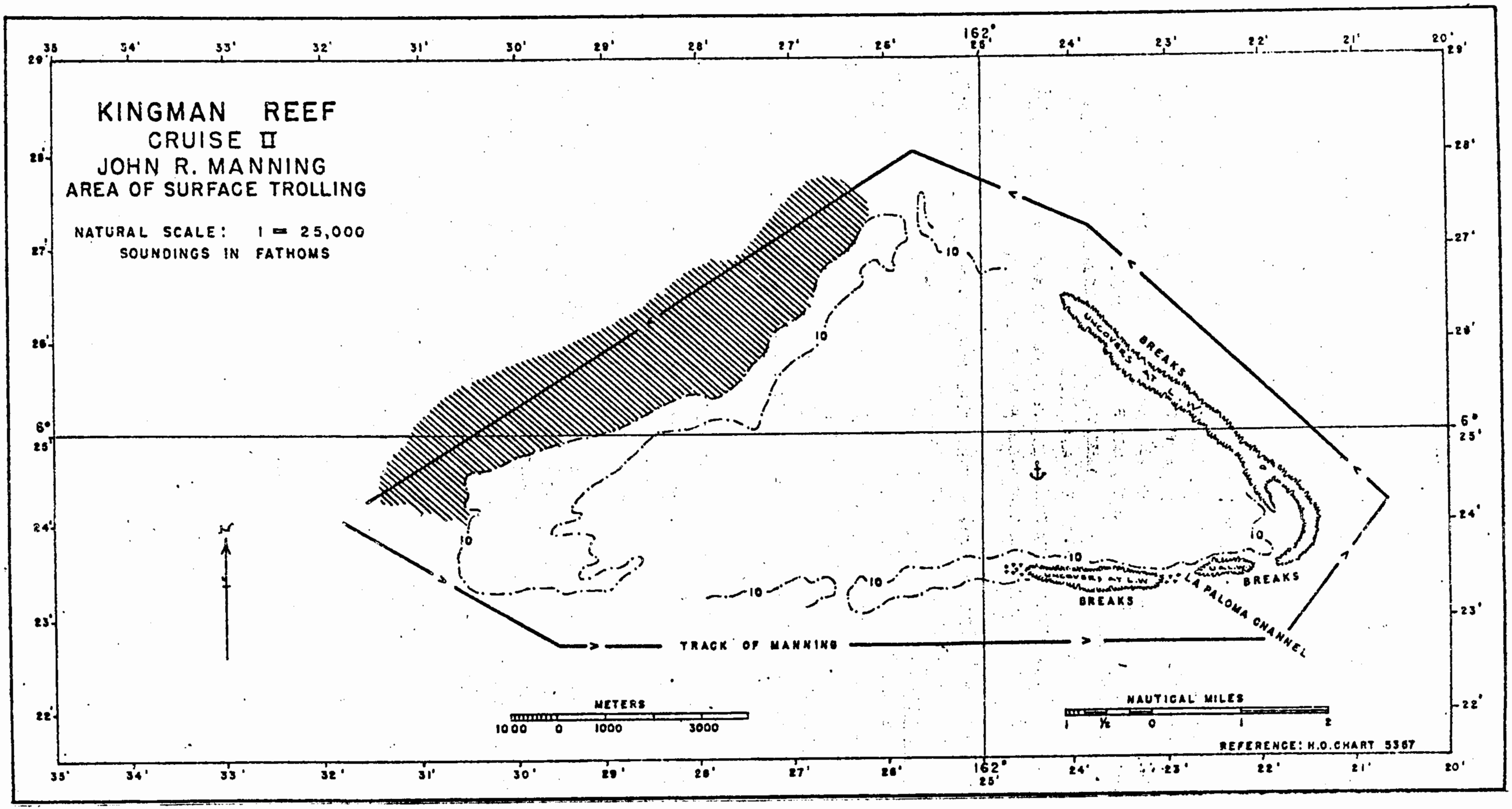


Figure 2.--Kingman Reef (from Bates 1950).

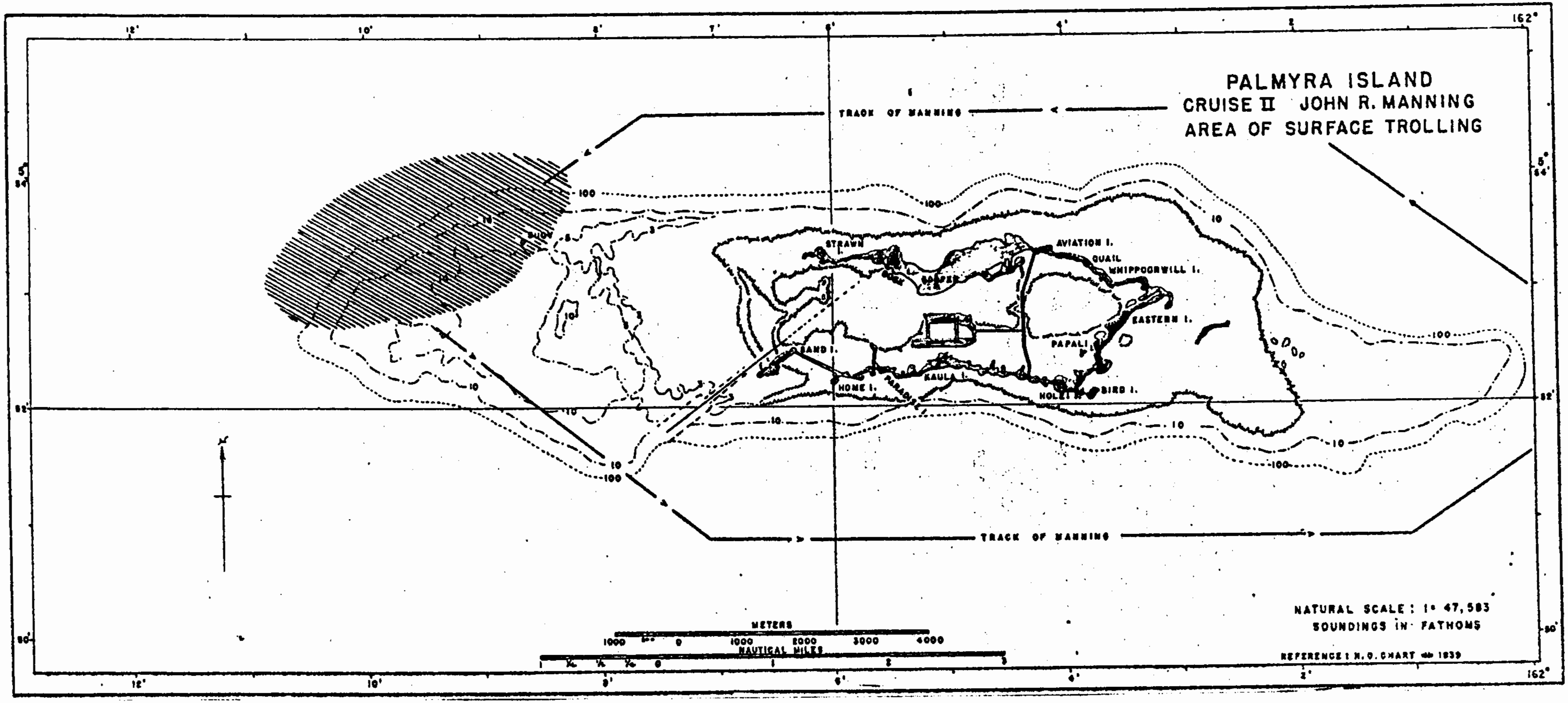


Figure 3.--Palmyra Island (from Bates 1950).

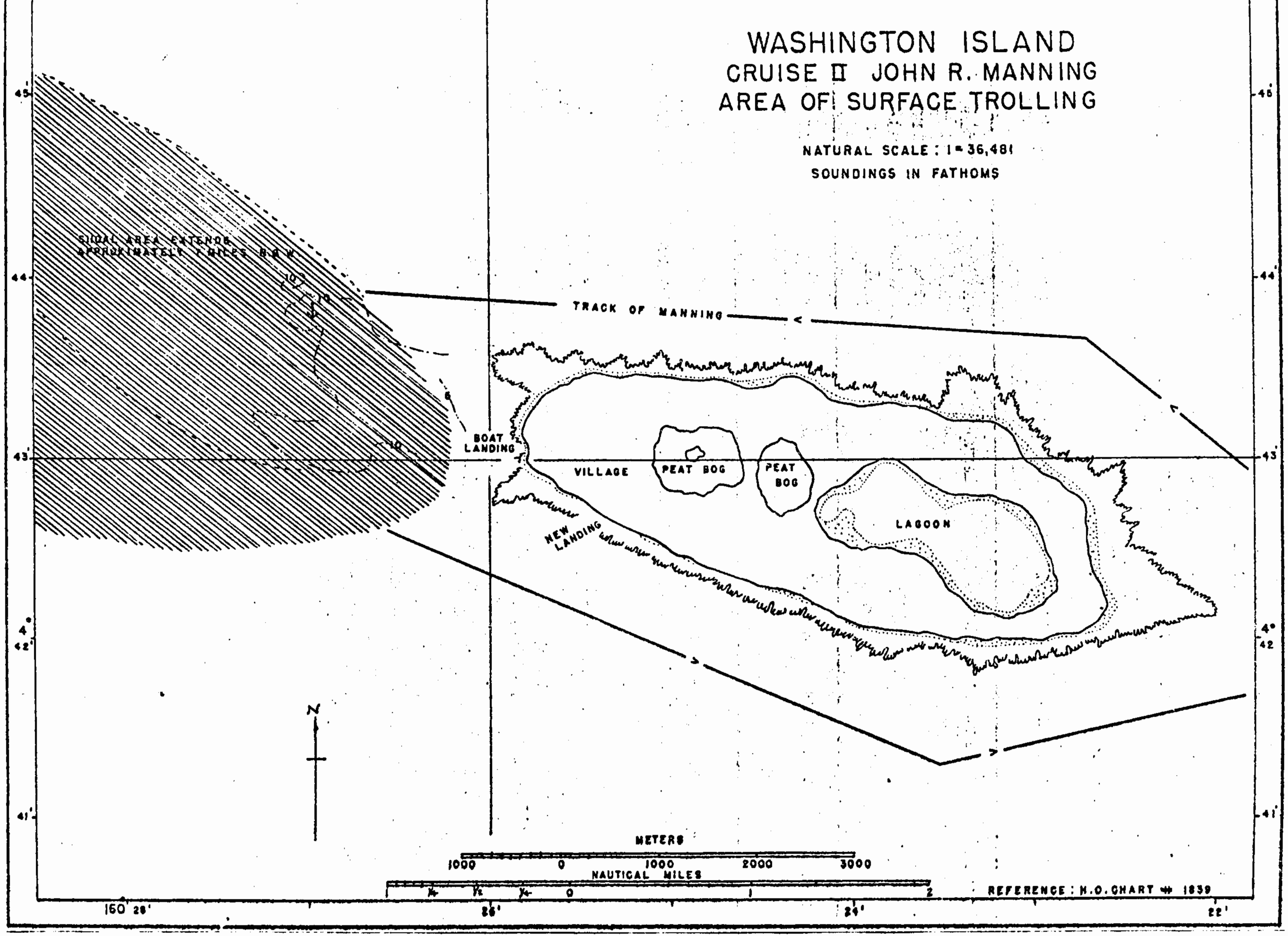


Figure 4.--Washington Island (from Bates 1950).

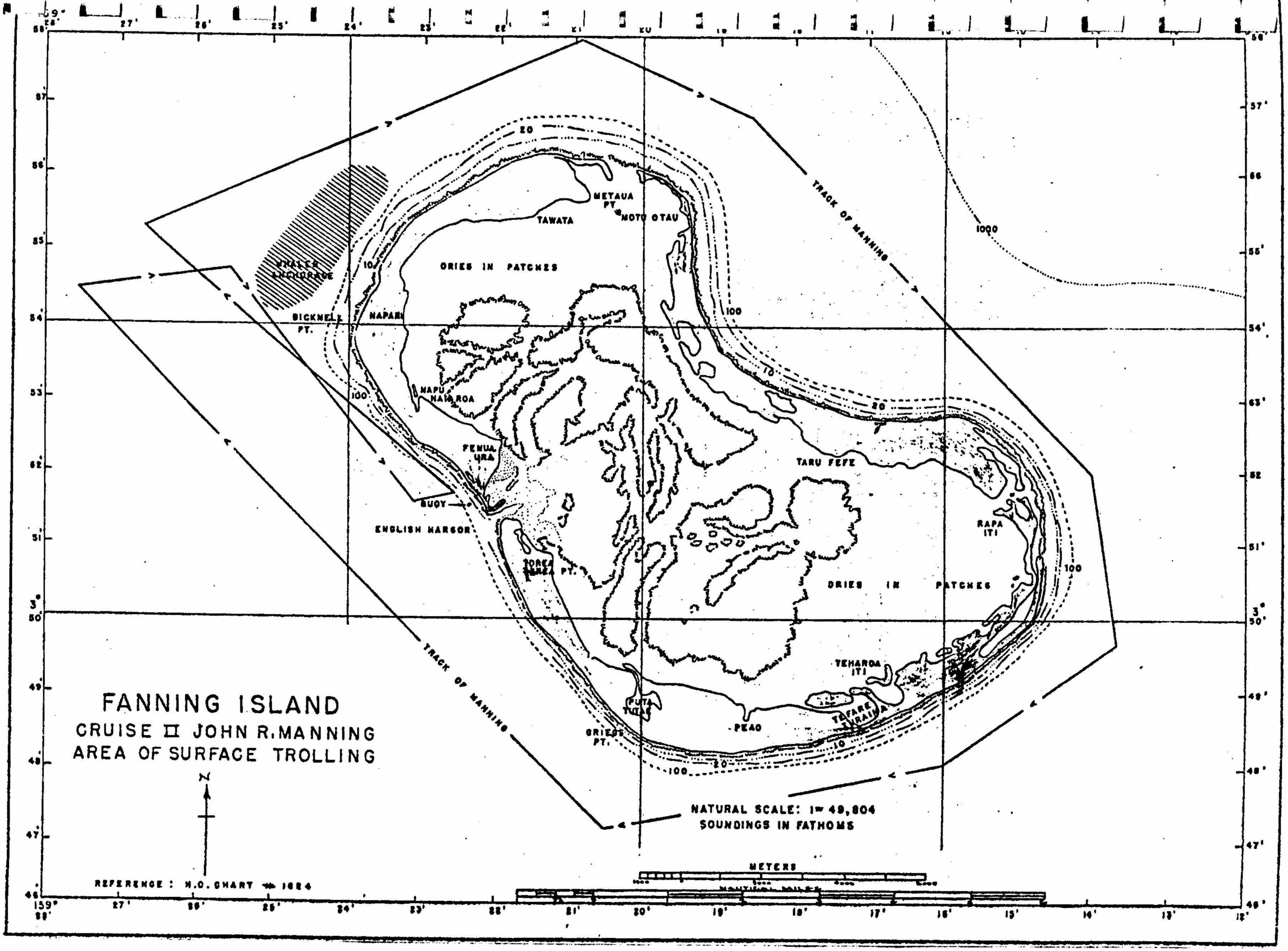


Figure 5.--Fanning Island (from Bates 1950).

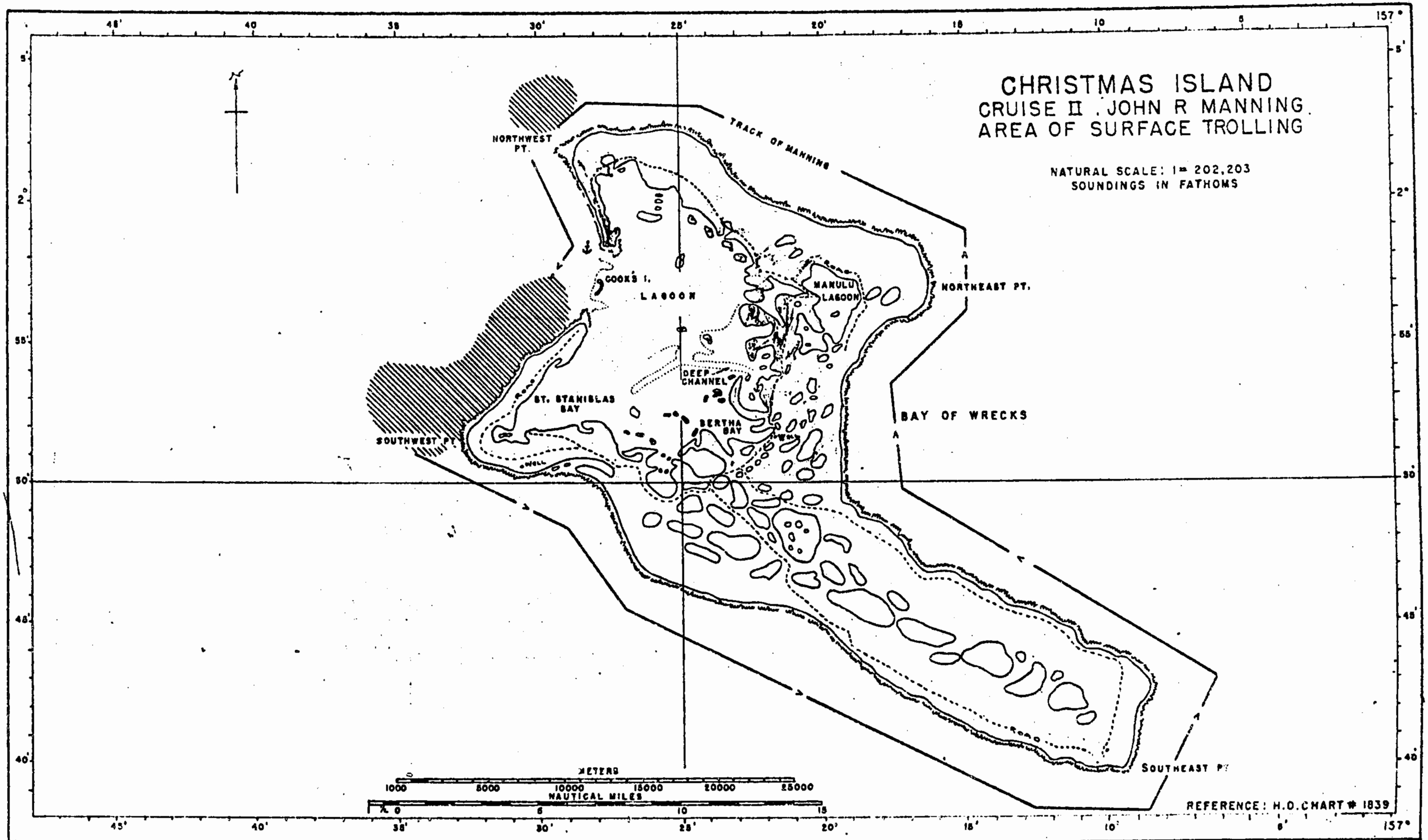


Figure 6.--Christmas Island (from Bates 1950).

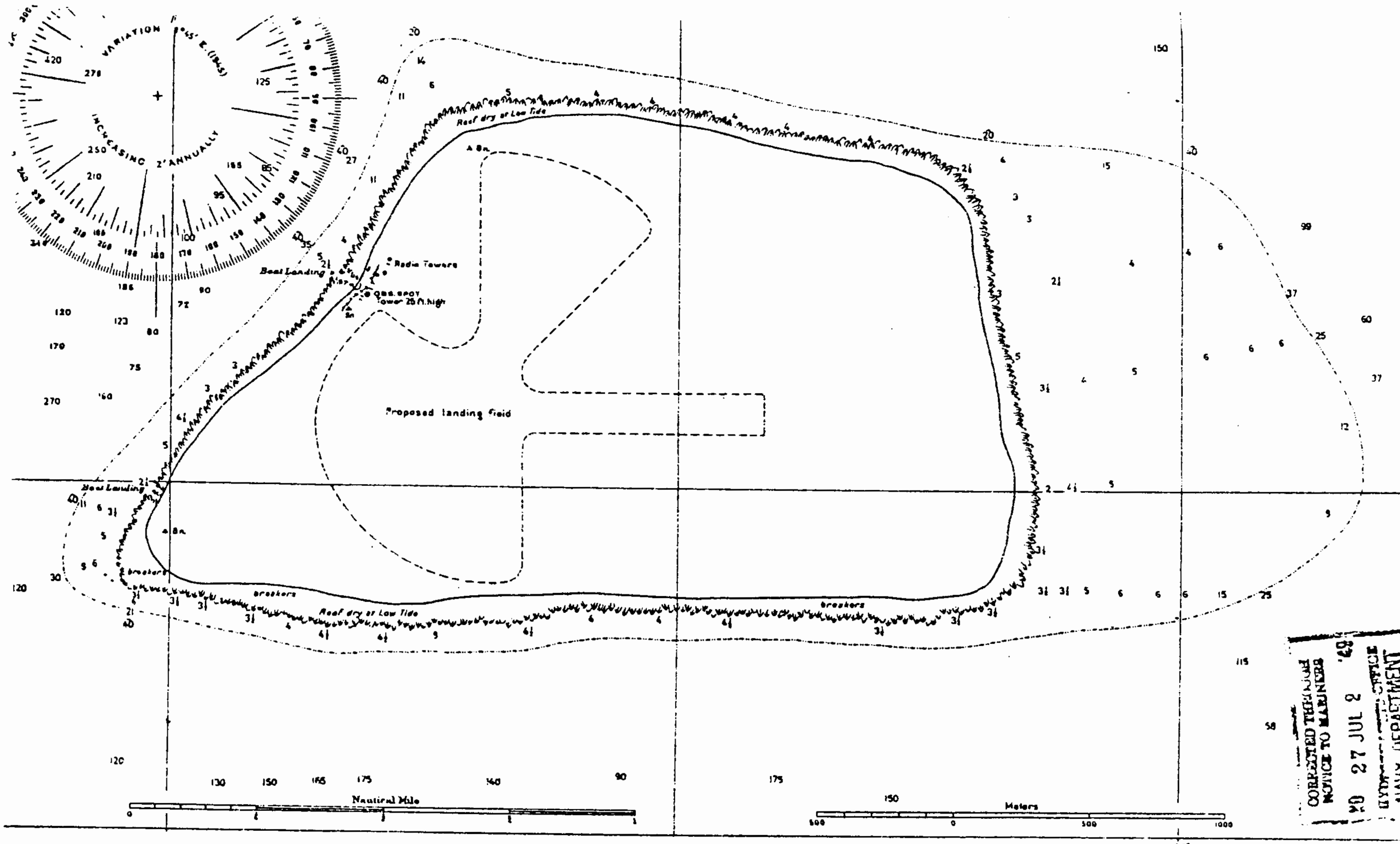


Figure 7.--Jarvis Island (from H. O. 1198, 11th ed., Sept. 1945).

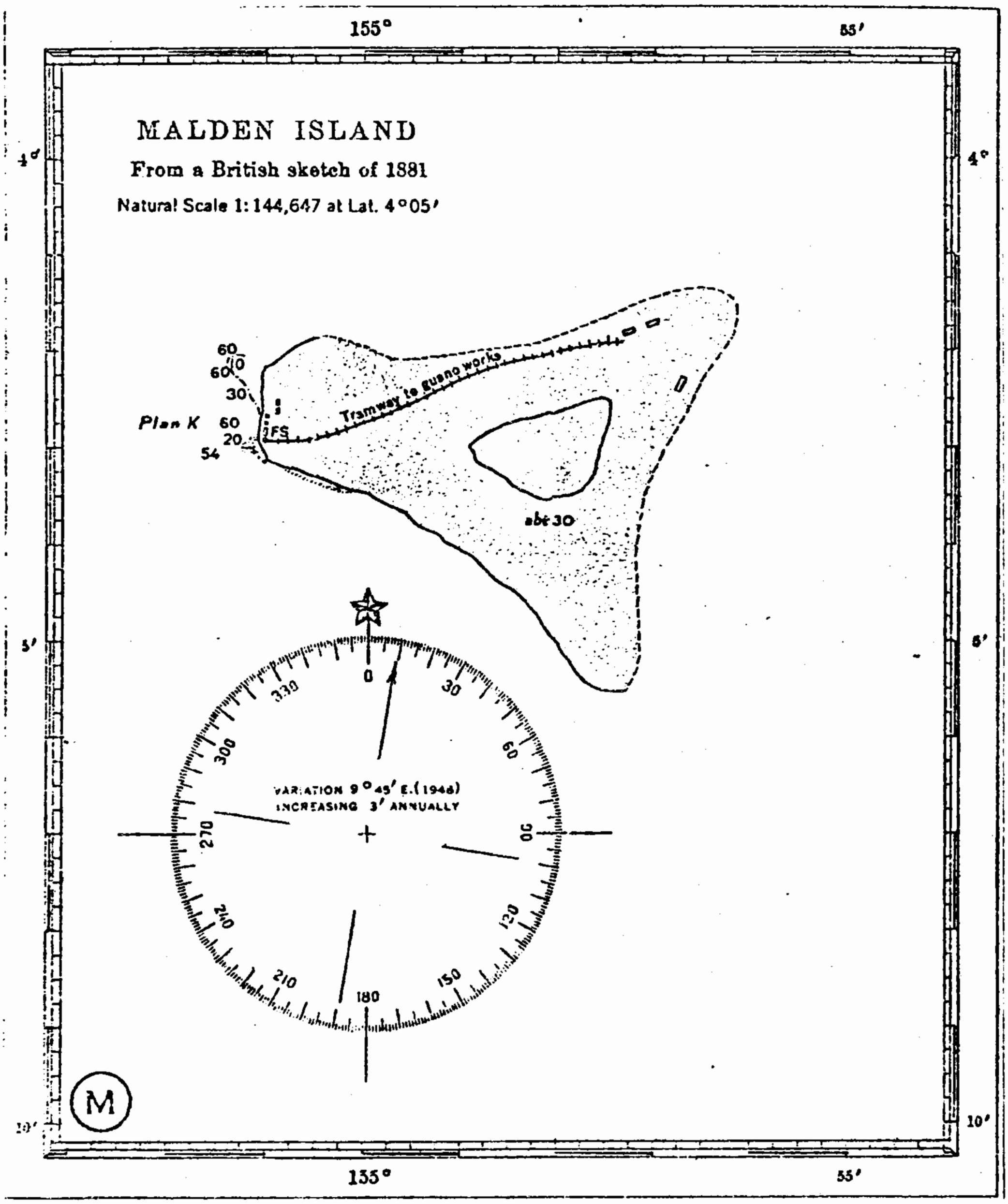


Figure 8.--Malden Island (from H. O. 1980, 9th ed., Mar. 1948).

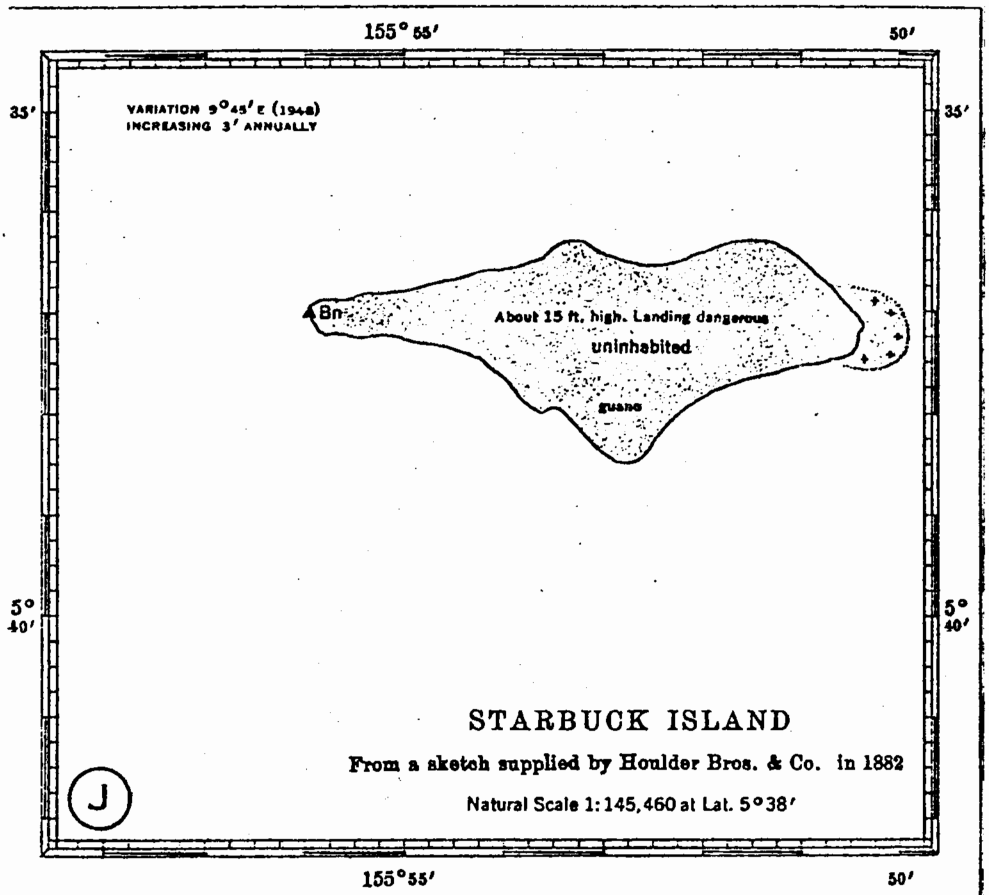


Figure 9.--Starbuck Island (from H. O. 1980, 9th ed., Mar. 1948).

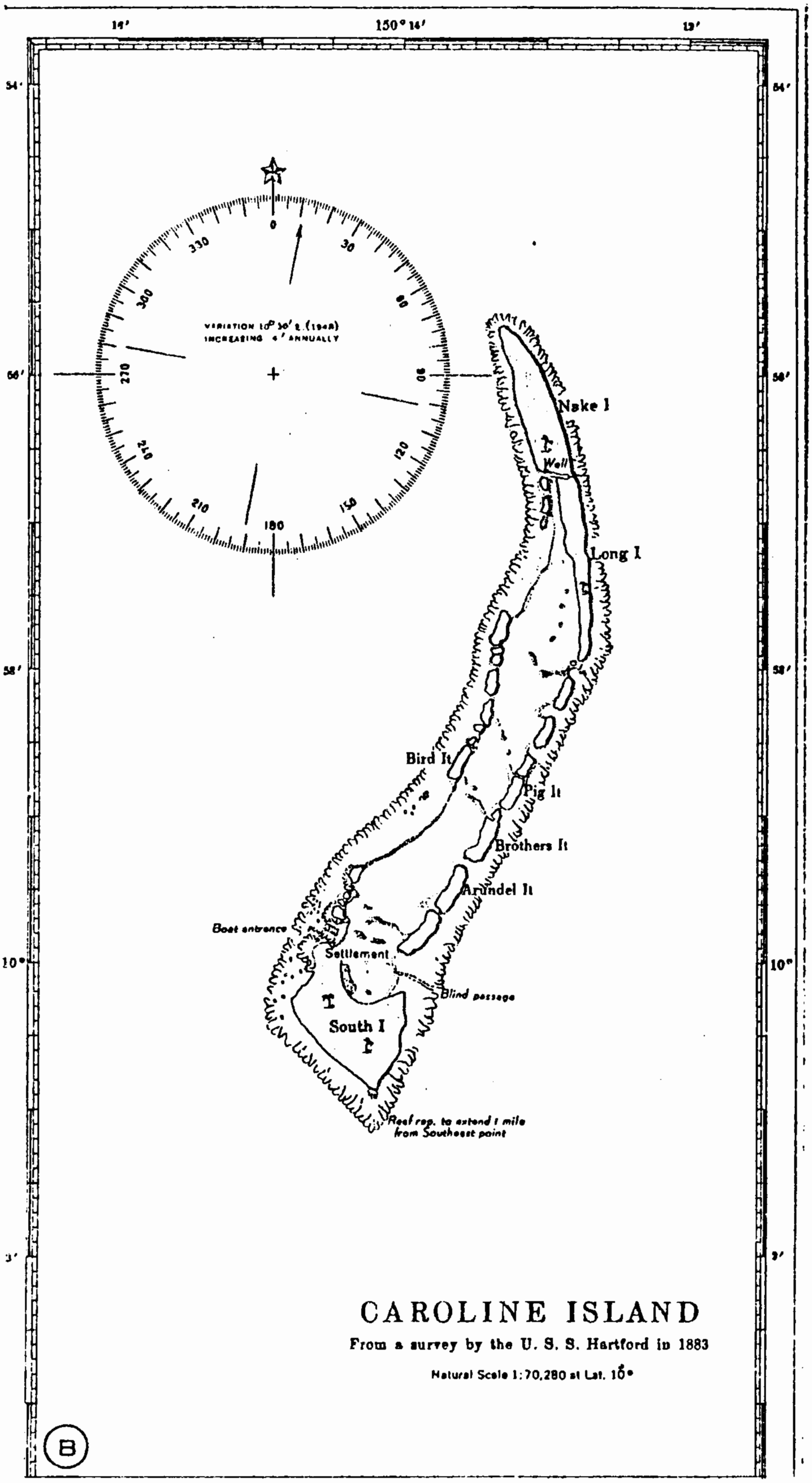


Figure 10.--Caroline Island (from H. O. 1980, 9th ed., Mar. 1948).

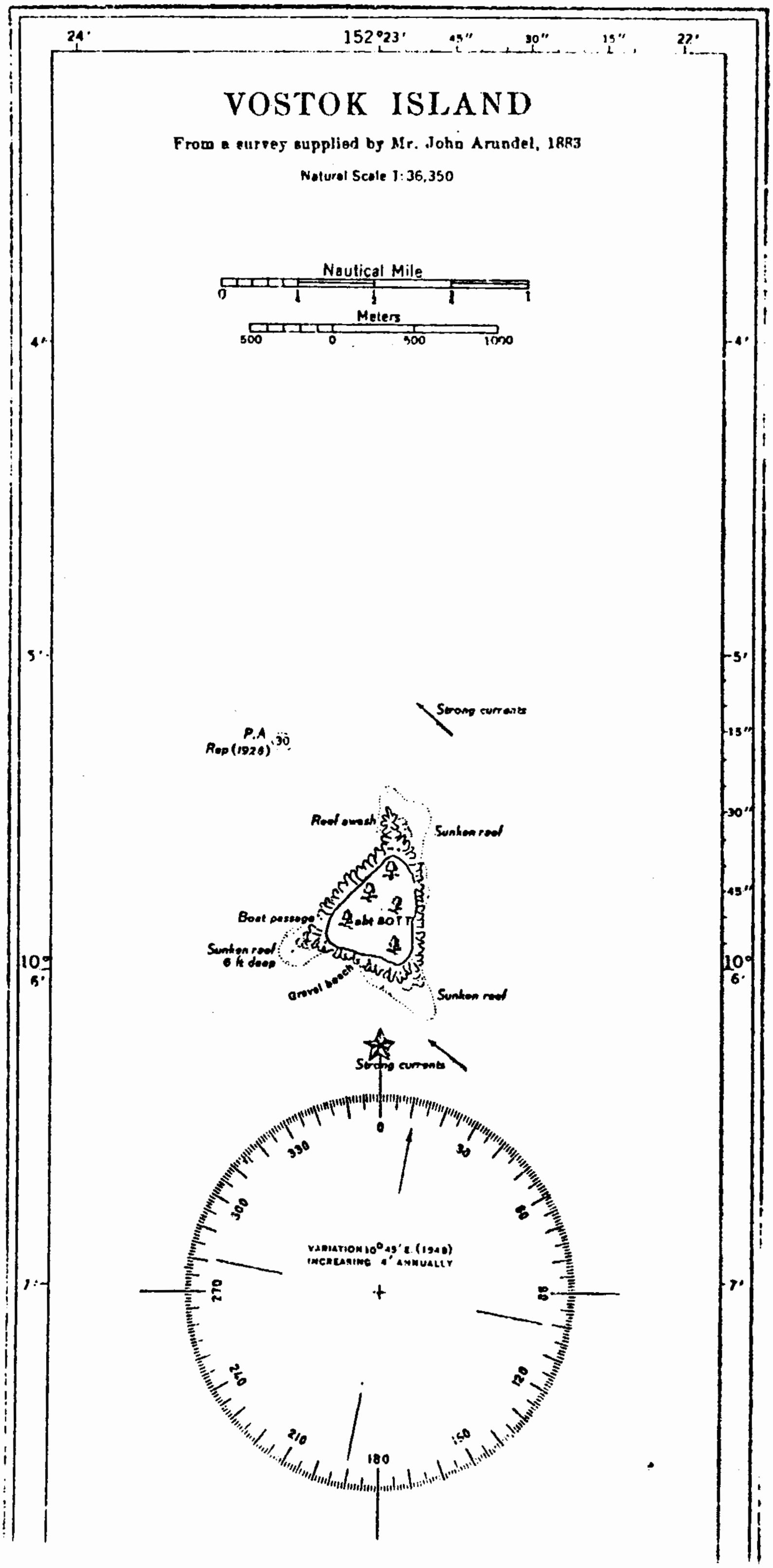


Figure 11.--Vostok Island (from H. O. 1980, 9th ed., Mar. 1948).

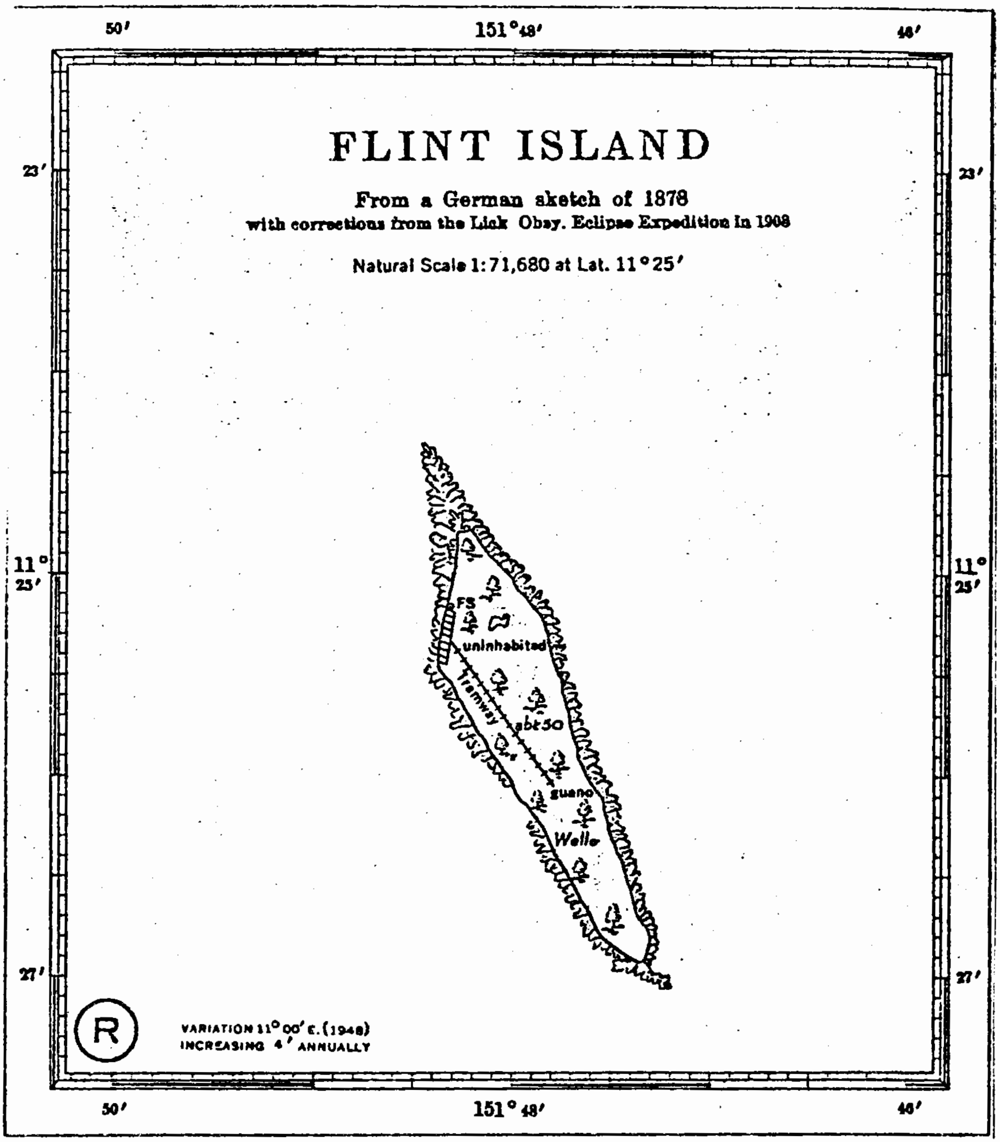


Figure 12.--Flint Island (from H. O. 1980, 9th ed., Mar. 1948).

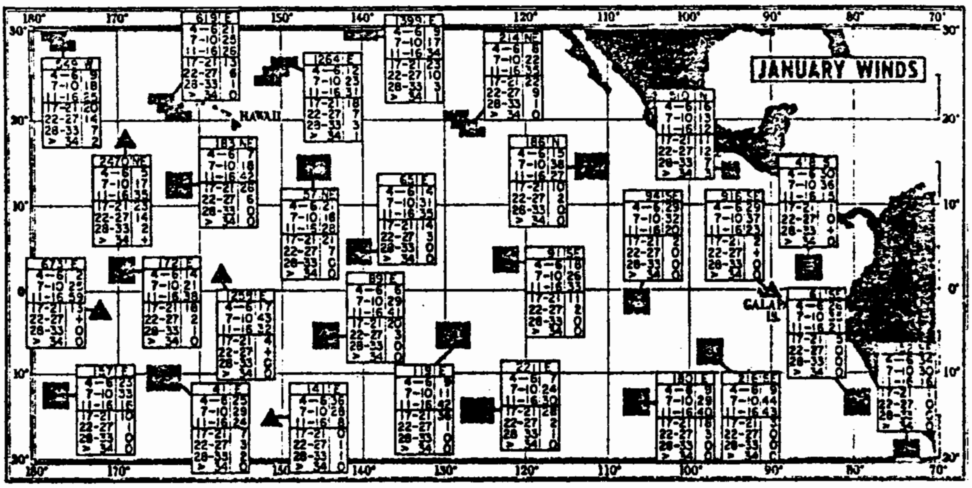


Figure 13.--January winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

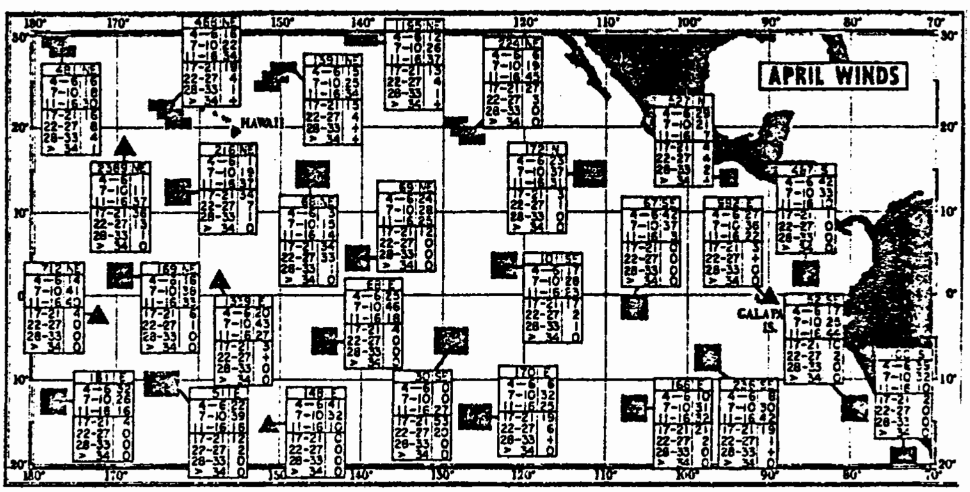


Figure 14.--April winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

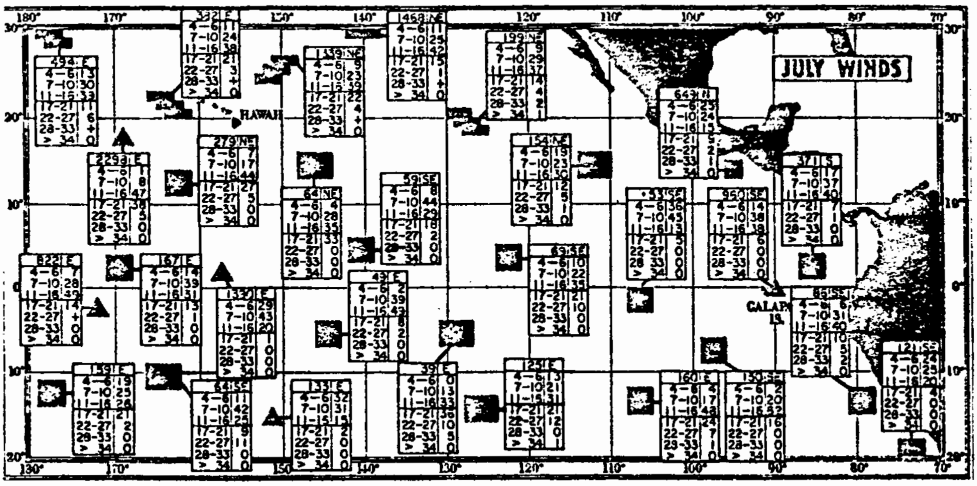


Figure 15.--July winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

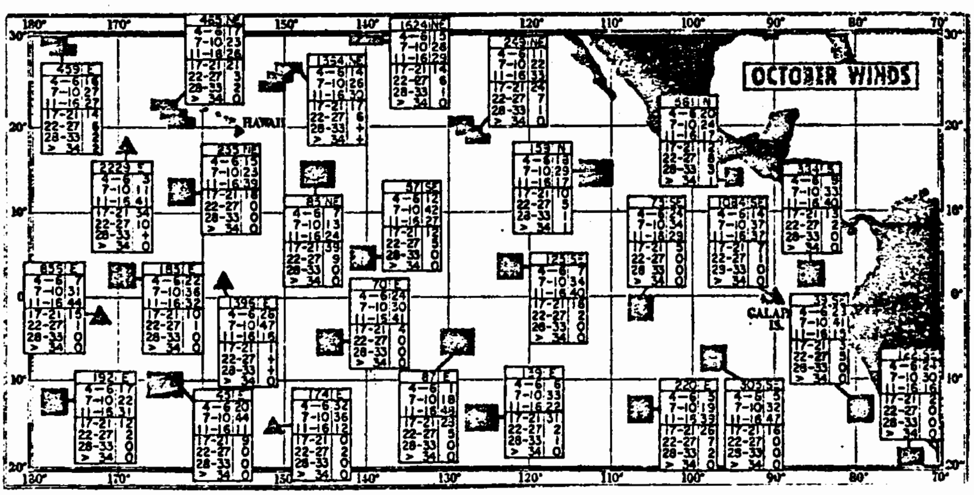


Figure 16.--October winds in the eastern and central equatorial Pacific Ocean (from BCF 1963).

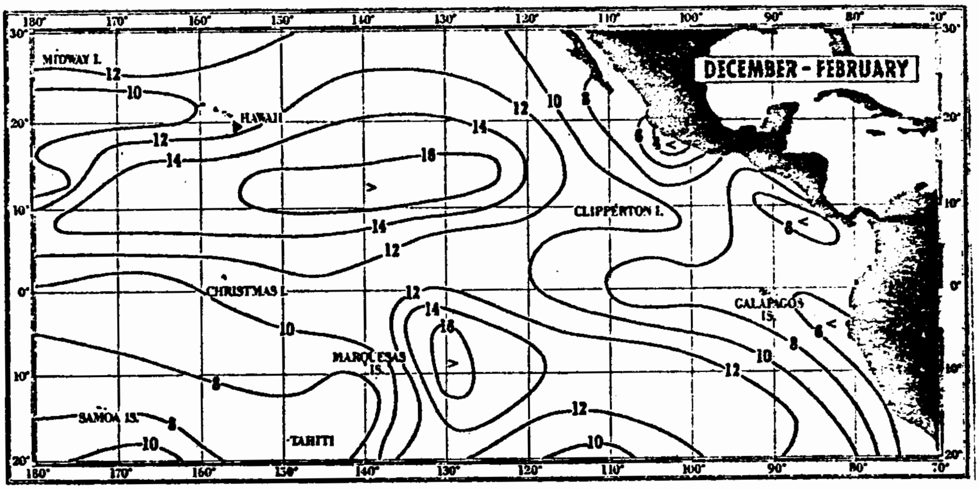


Figure 17.--Average wind velocities, December-February, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

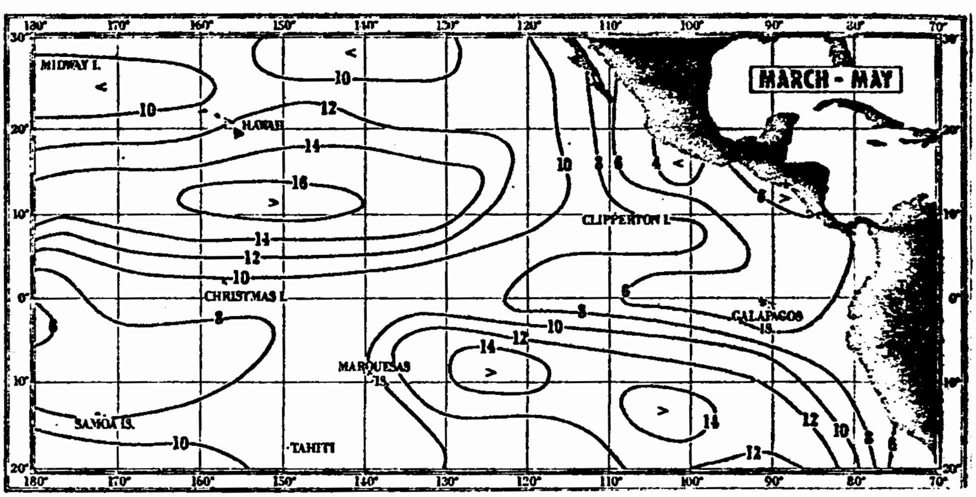


Figure 18.--Average wind velocities, March-May, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

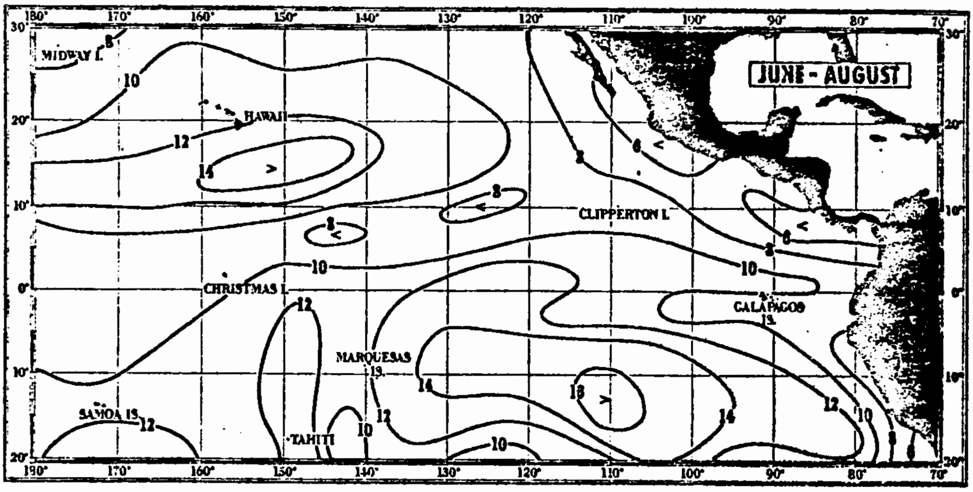


Figure 19.--Average wind velocities, June-August, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

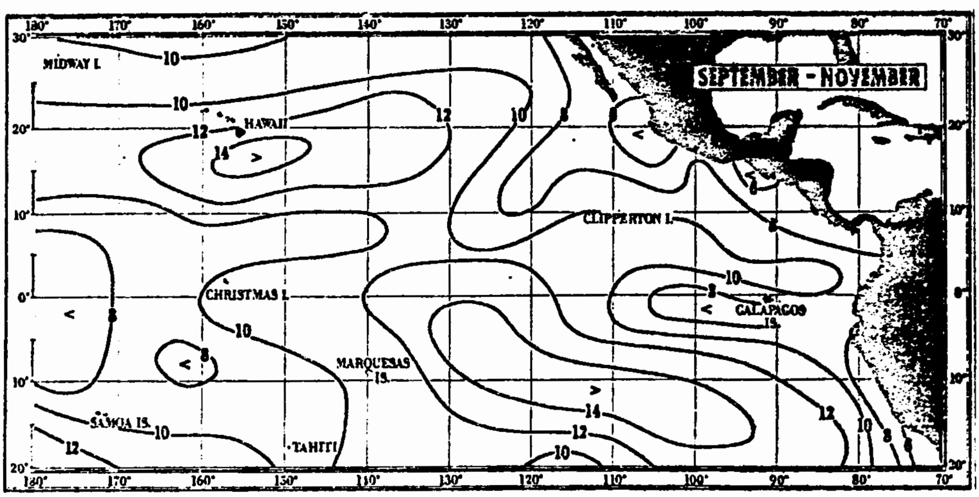


Figure 20.--Average wind velocities, September-November, in the eastern and central equatorial Pacific Ocean (from BCF 1963).

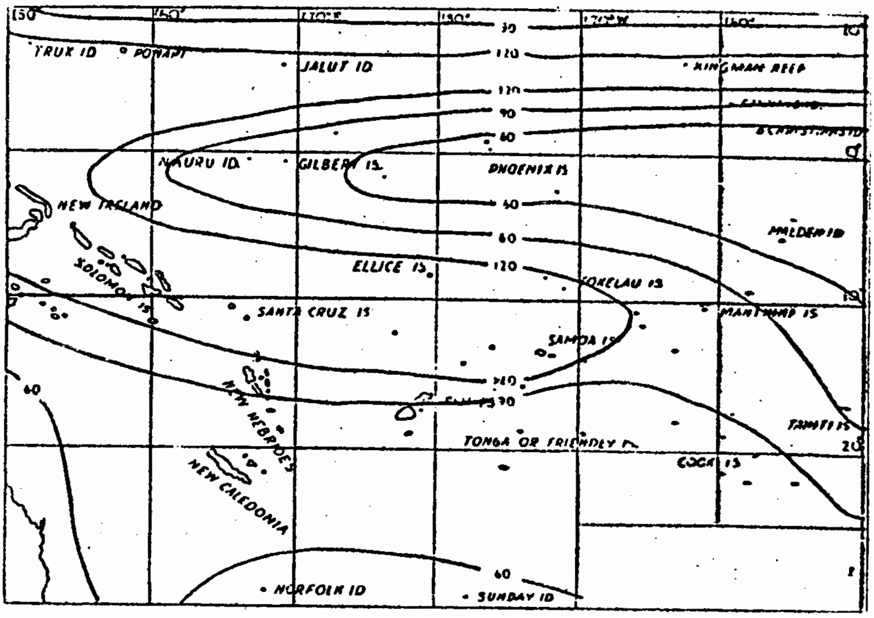


Figure 21.--Average annual rainfall in inches (from Seelye 1950).

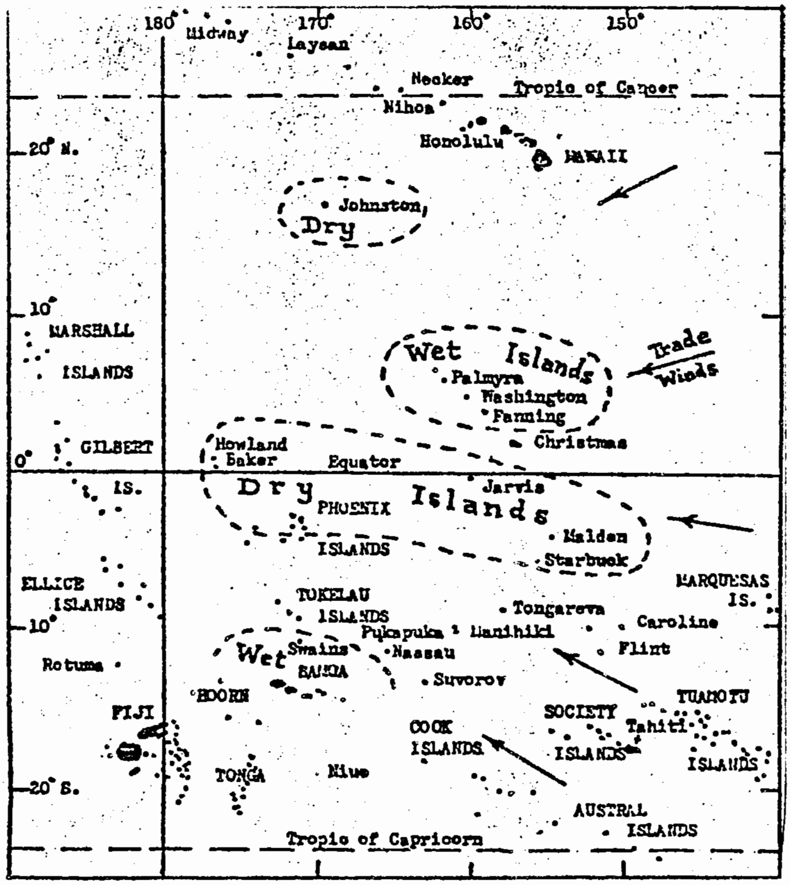


Figure 22.--Location of wet and dry islands in the central equatorial Pacific Ocean (from Bryan 1941).

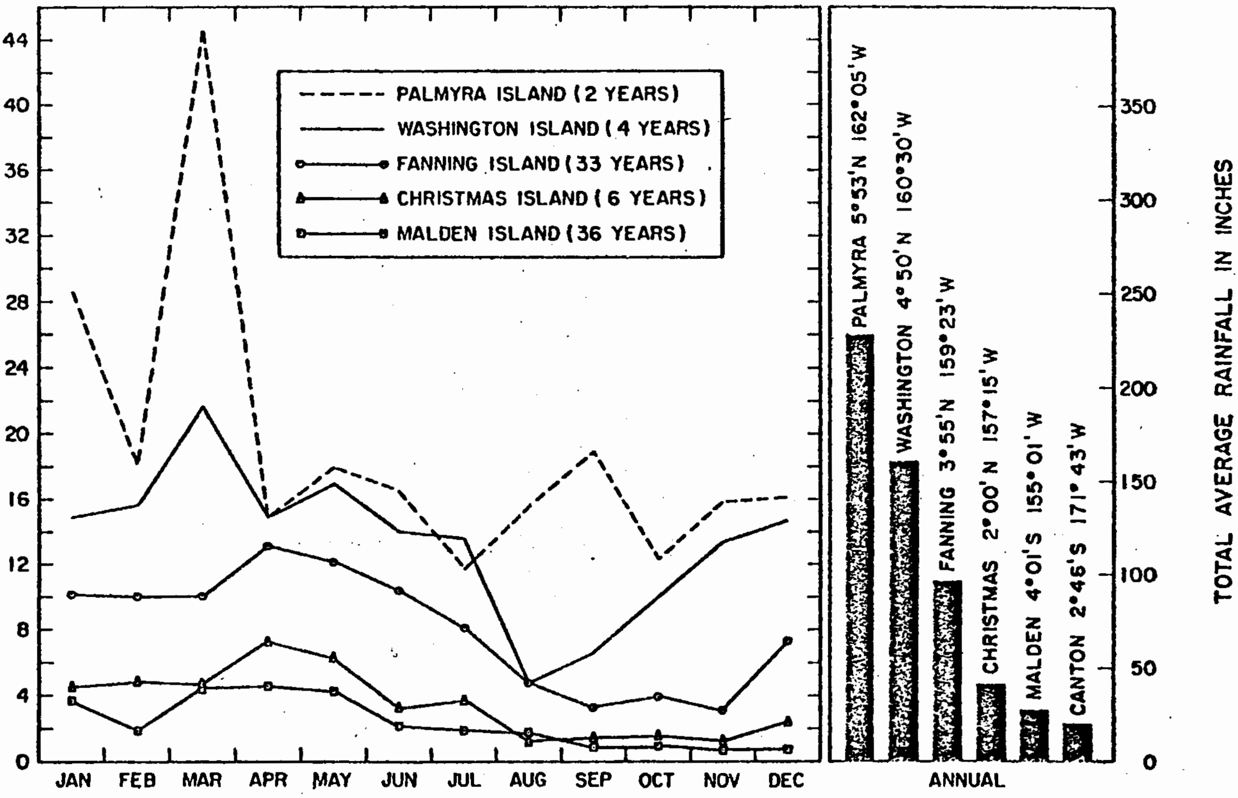


Figure 23.--Average monthly and annual rainfall for Palmyra, Washington, Fanning, Christmas, Malden, and Canton Islands (from Austin 1954b).

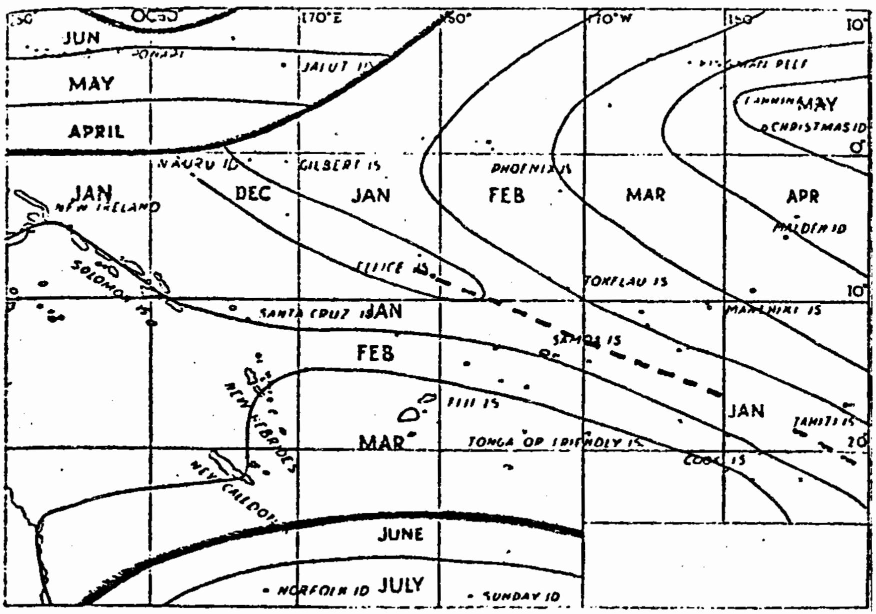


Figure 24.--Month of highest average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

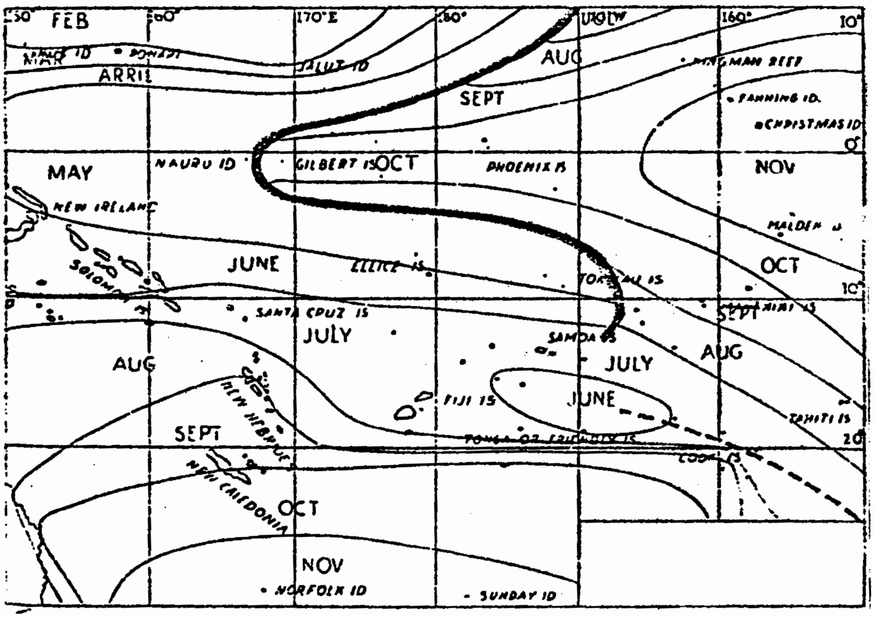


Figure 25.--Month of least average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

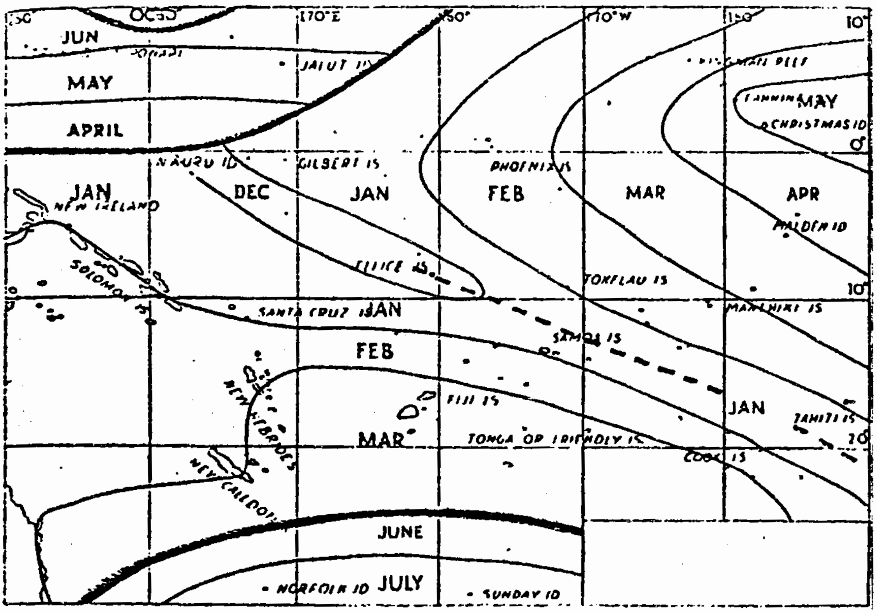


Figure 24.--Month of highest average rainfall in the central equatorial Pacific Ocean (from Seelye 1950).

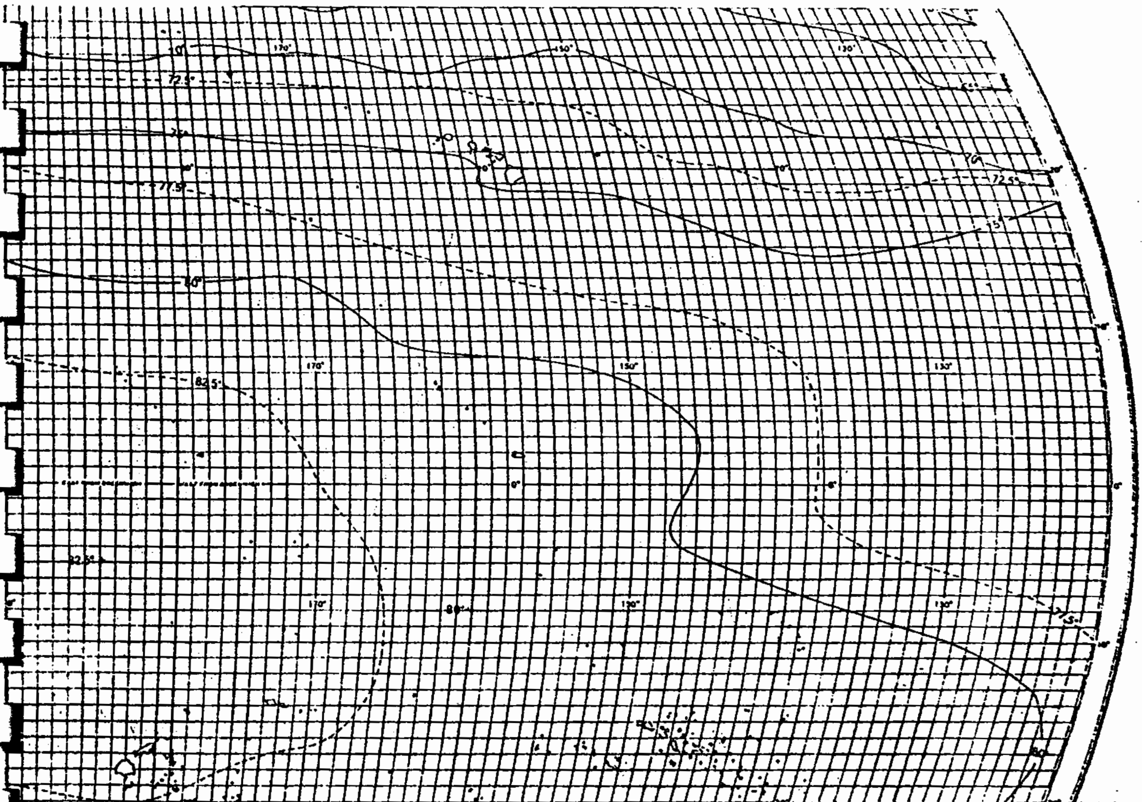


Figure 27a.—Surface temperature in the central equatorial Pacific Ocean in January (from U. S. Navy Hydrographic Office 1944).

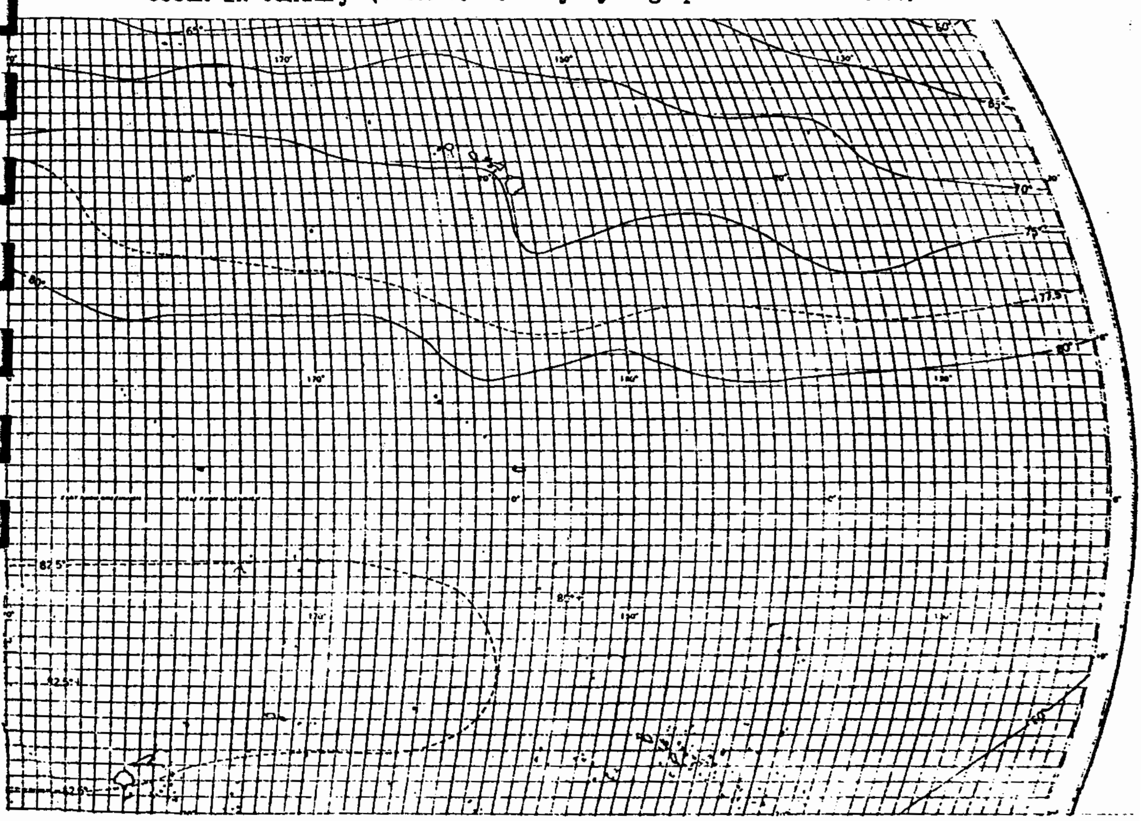


Figure 27b.—Surface temperature in the central equatorial Pacific Ocean in February (from U. S. Navy Hydrographic Office 1944).

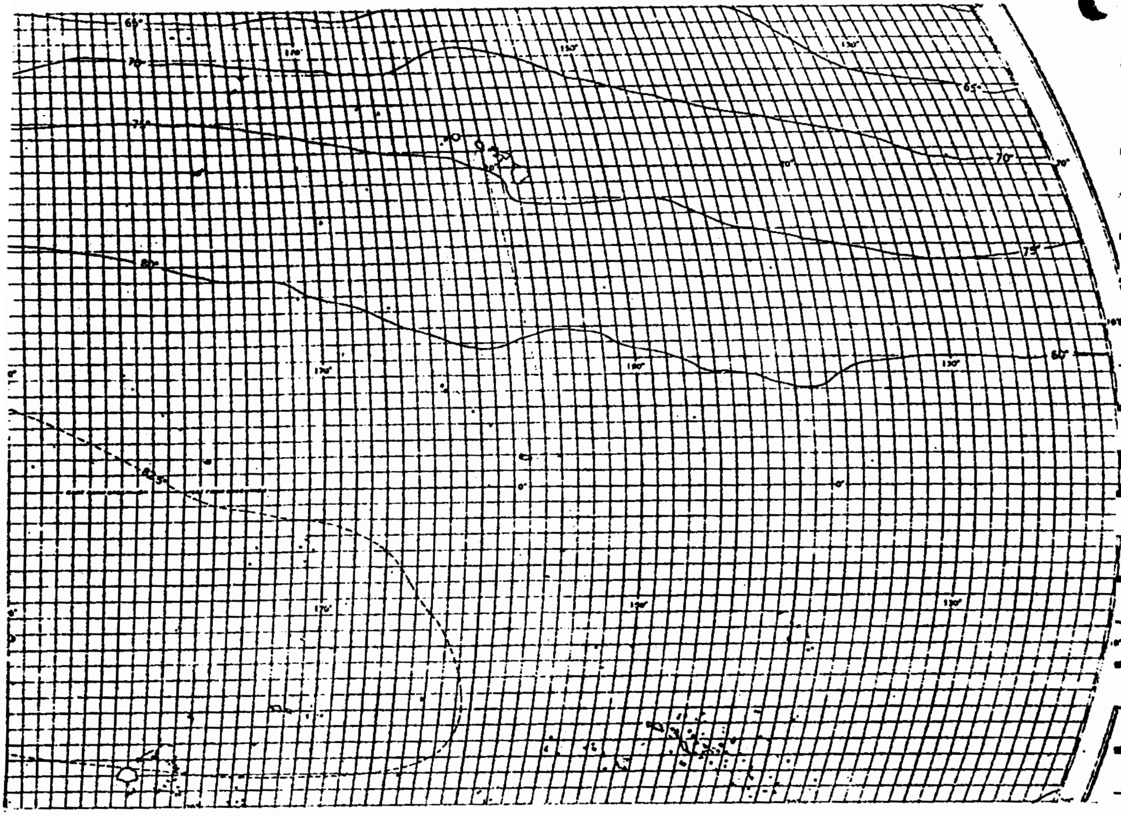


Figure 27c.--Surface temperature in the central equatorial Pacific Ocean in March (from U. S. Navy Hydrographic Office 1944).

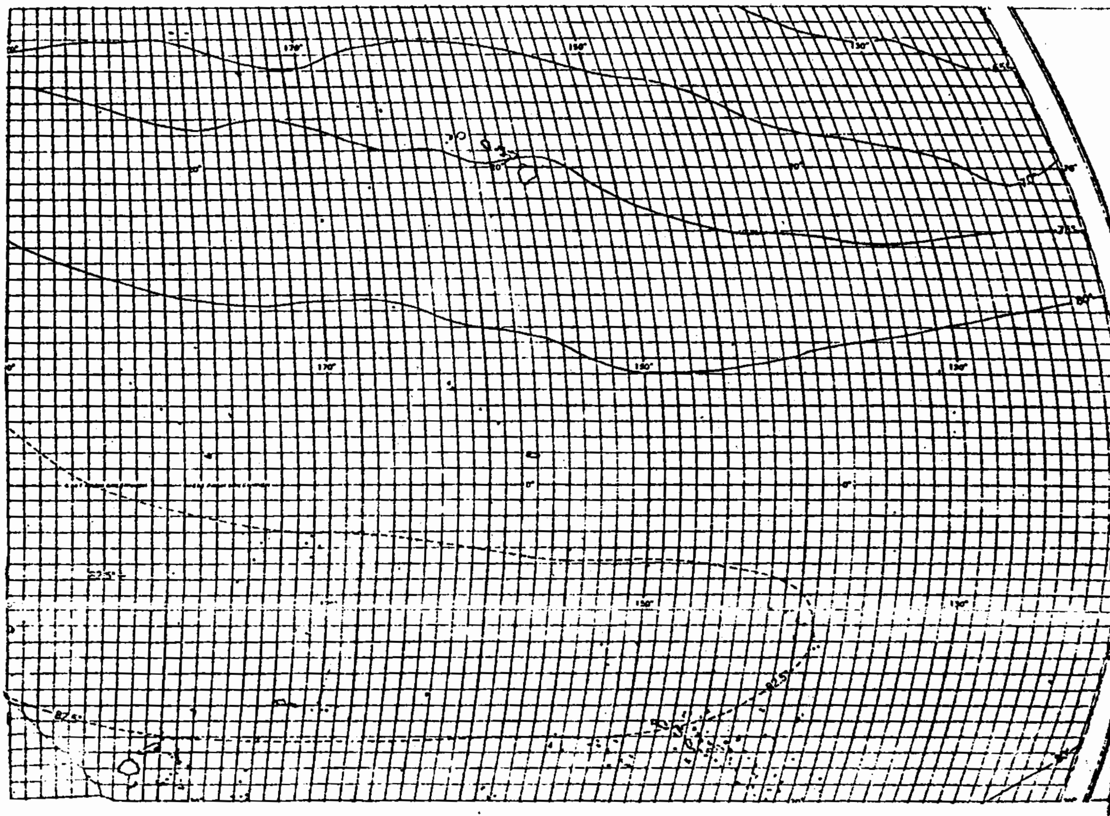


Figure 27d.--Surface temperature in the central equatorial Pacific Ocean

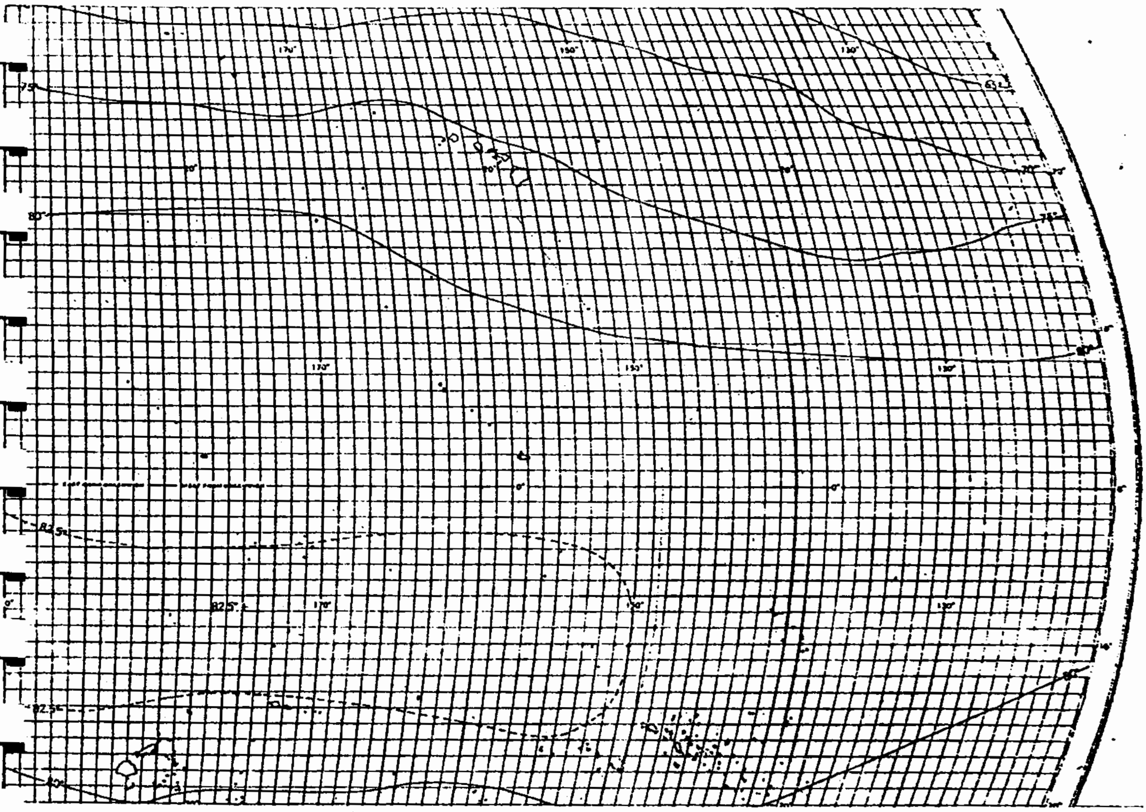


Figure 27e.--Surface temperature in the central equatorial Pacific Ocean in May (from U. S. Navy Hydrographic Office 1944).

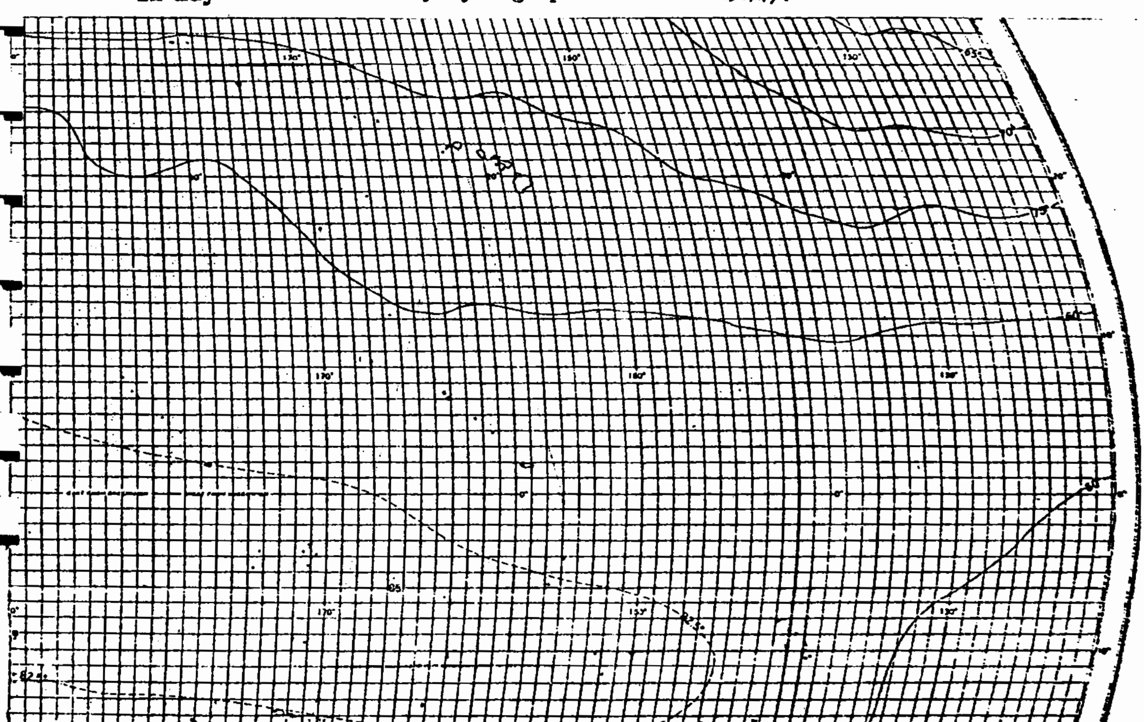


Figure 27f.--Surface temperature in the central equatorial Pacific Ocean in June (from U. S. Navy Hydrographic Office 1944).

Figure 27g.—Surface temperature in the central equatorial Pacific Ocean in July (from U. S. Navy Hydrographic Office 1944).

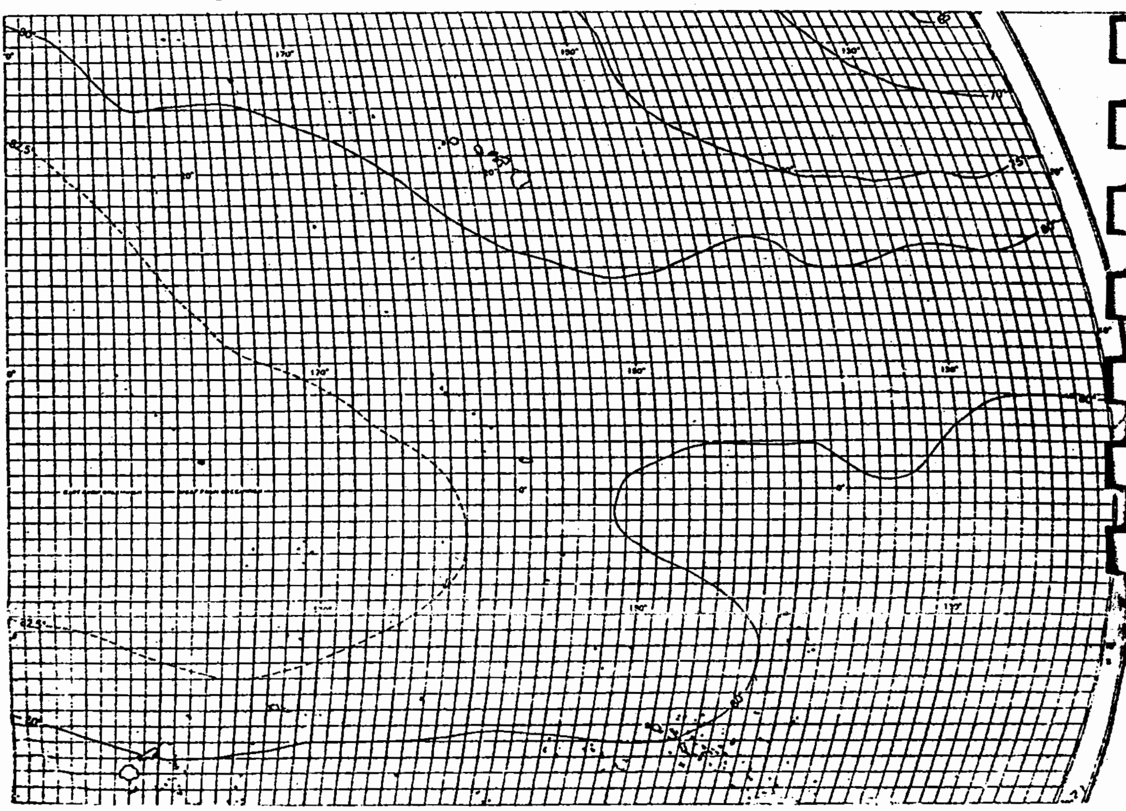


Figure 27h.—Surface temperature in the central equatorial Pacific Ocean

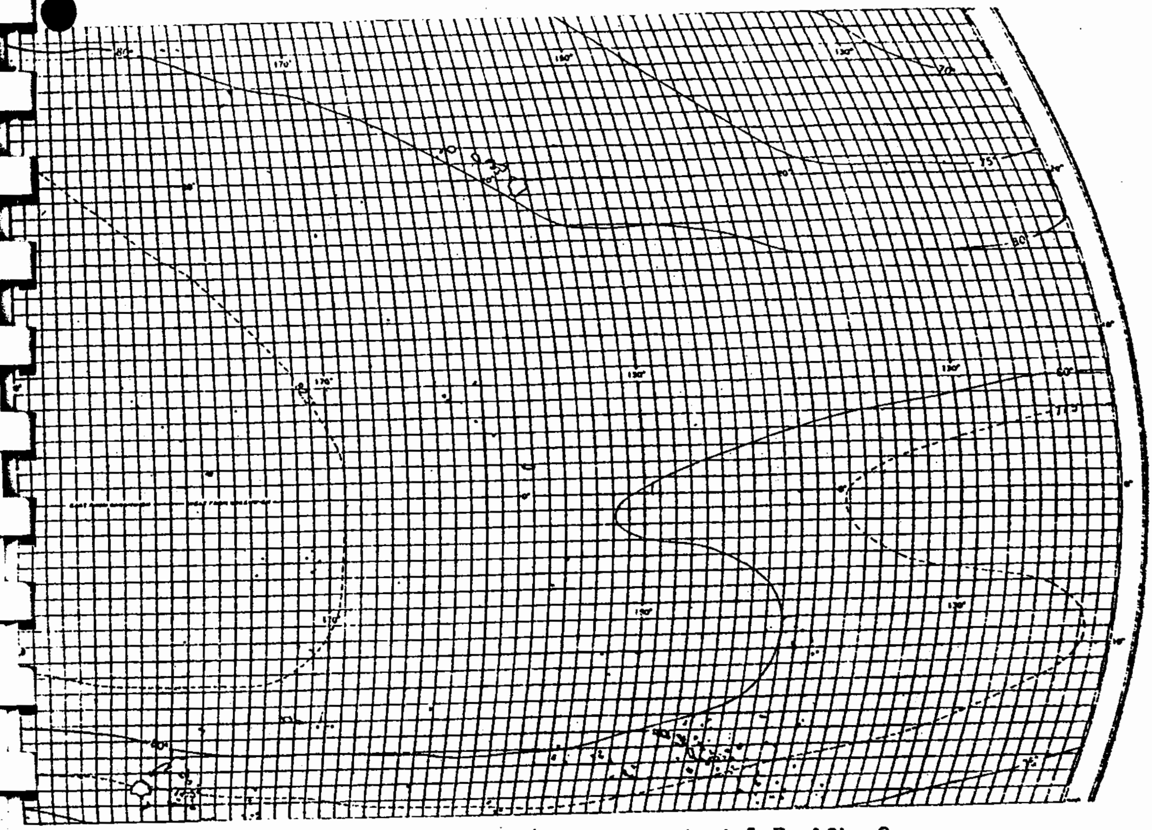


Figure 27i.--Surface temperature in the central equatorial Pacific Ocean in September (from U. S. Navy Hydrographic Office 1944).

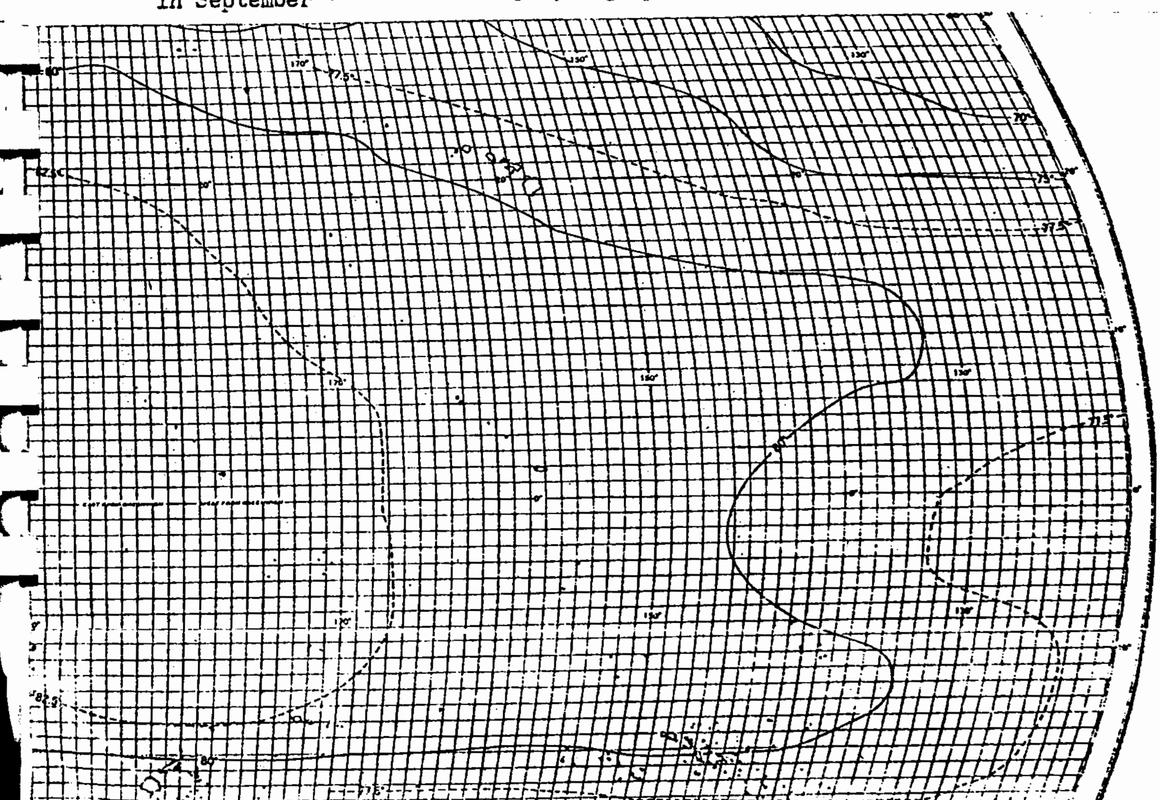


Figure 27j.--Surface temperature in the central equatorial Pacific Ocean in October (from U. S. Navy Hydrographic Office 1944).

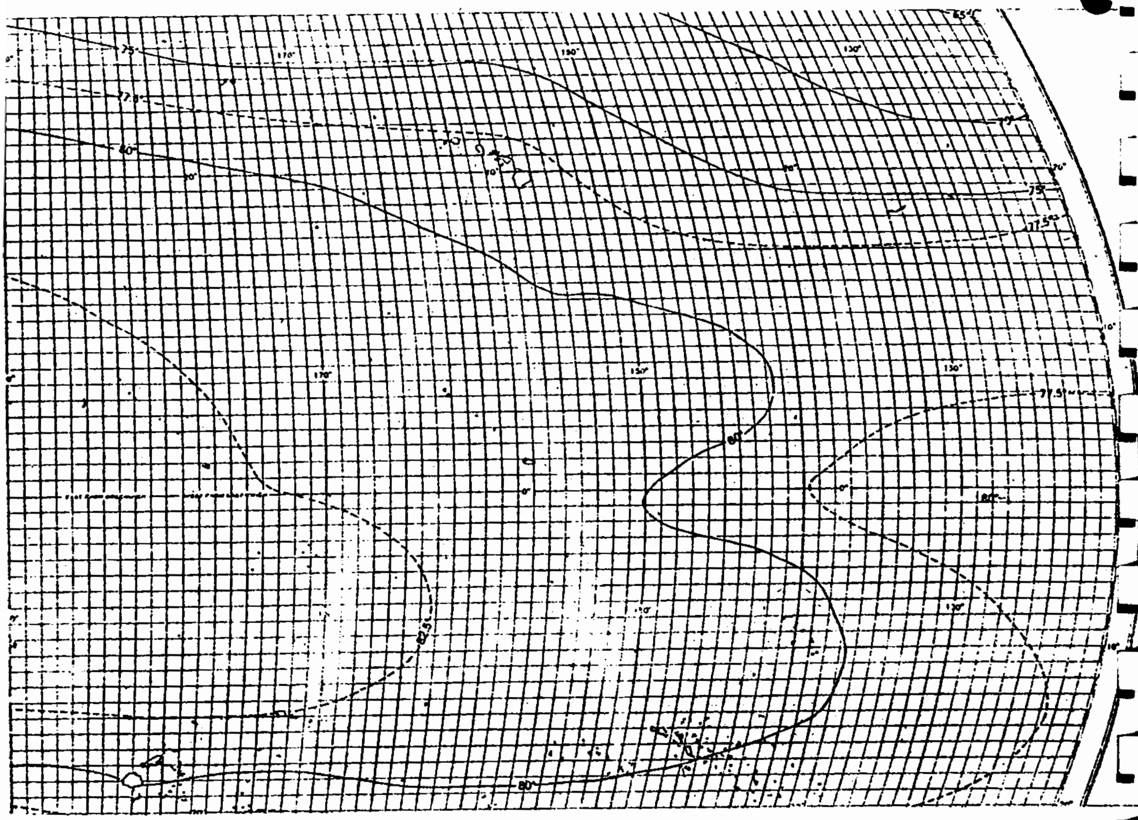


Figure 27k.--Surface temperature in the central equatorial Pacific Ocean

in November (from U. S. Navy Hydrographic Office 1944).

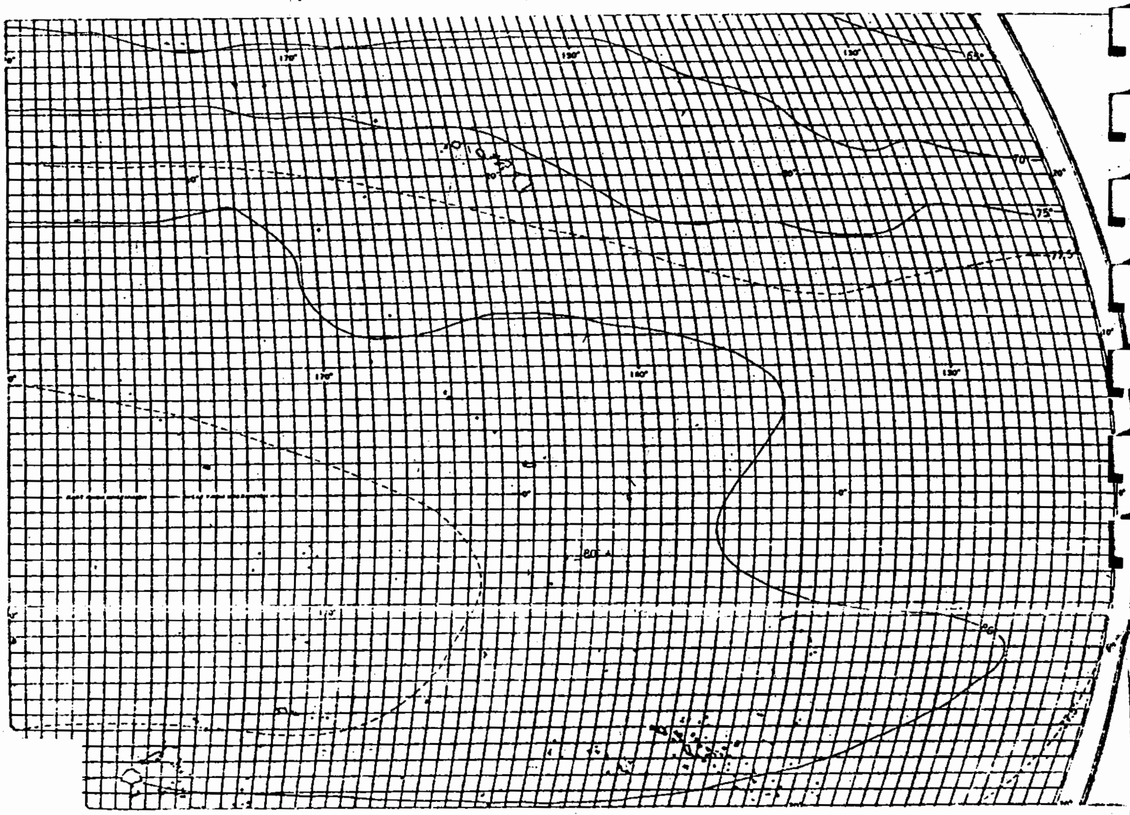


Figure 27l.--Surface temperature in the central equatorial Pacific Ocean

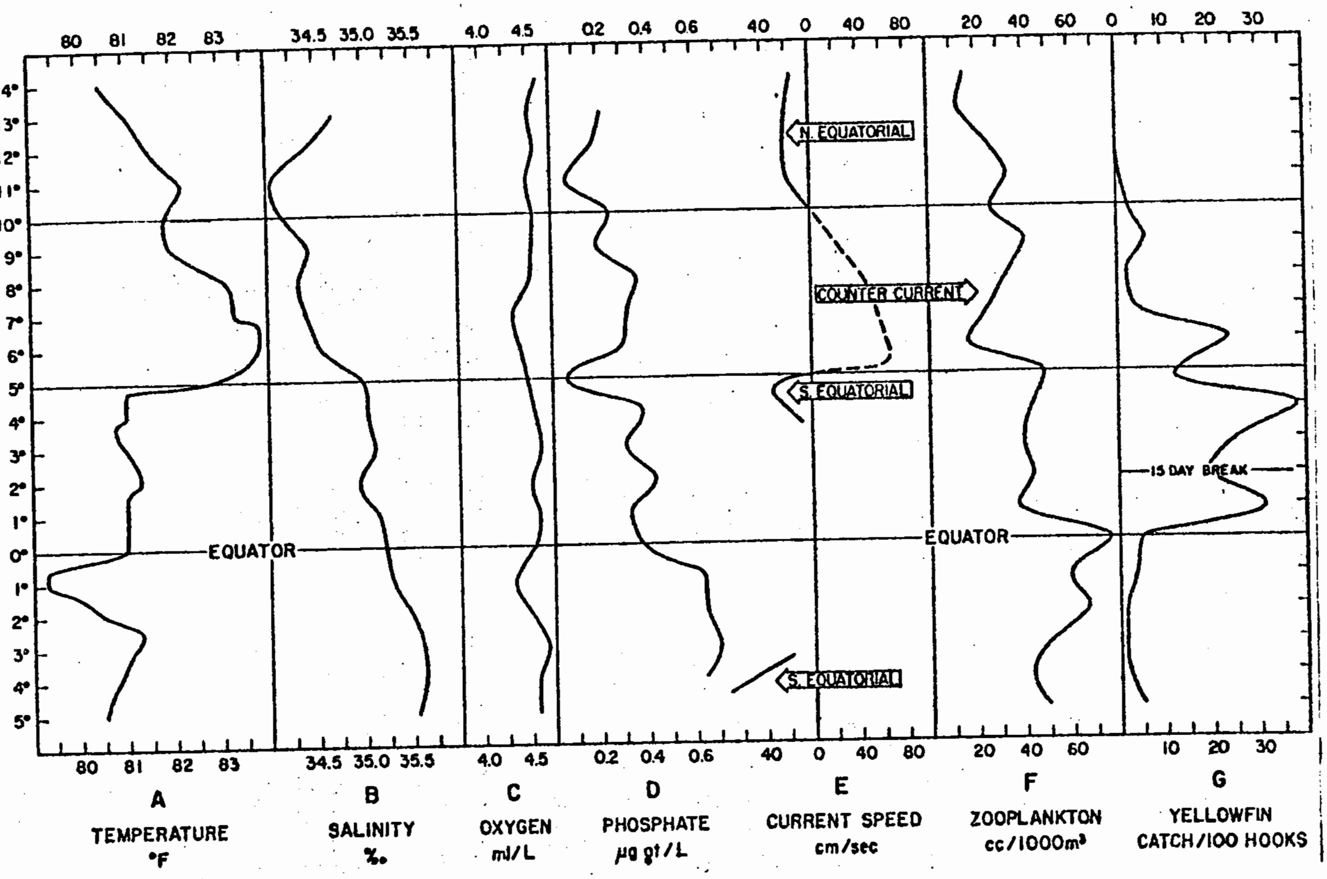


Figure 28.--Summary of various oceanographic and biological data, <u>Hugh</u> <u>M</u>. <u>Smith</u> cruise 11, August-October 1951. Northbound section, panels (A) through (F), southbound section panel (G) (from Austin 1954a).

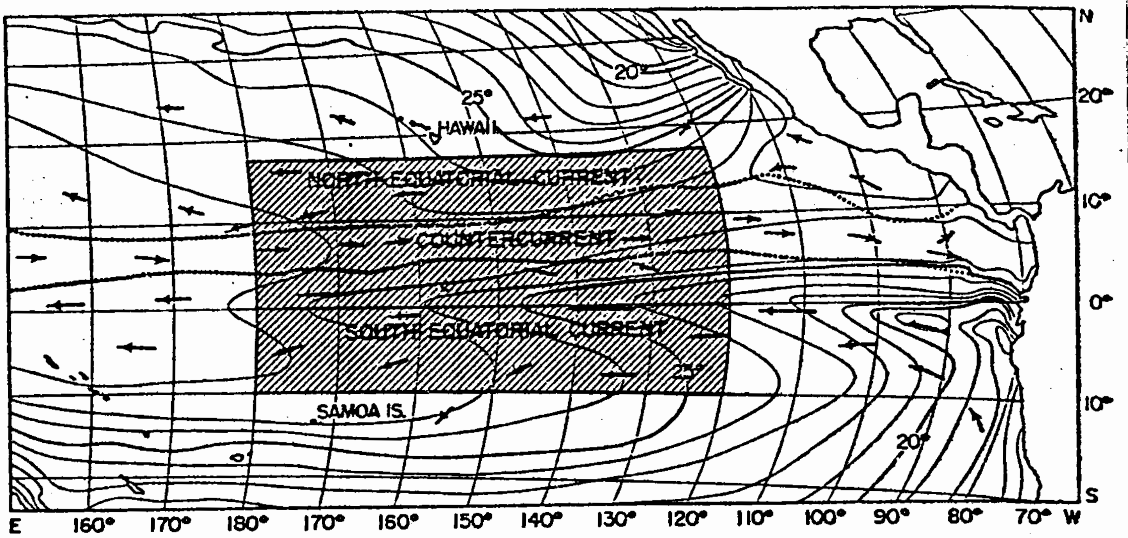
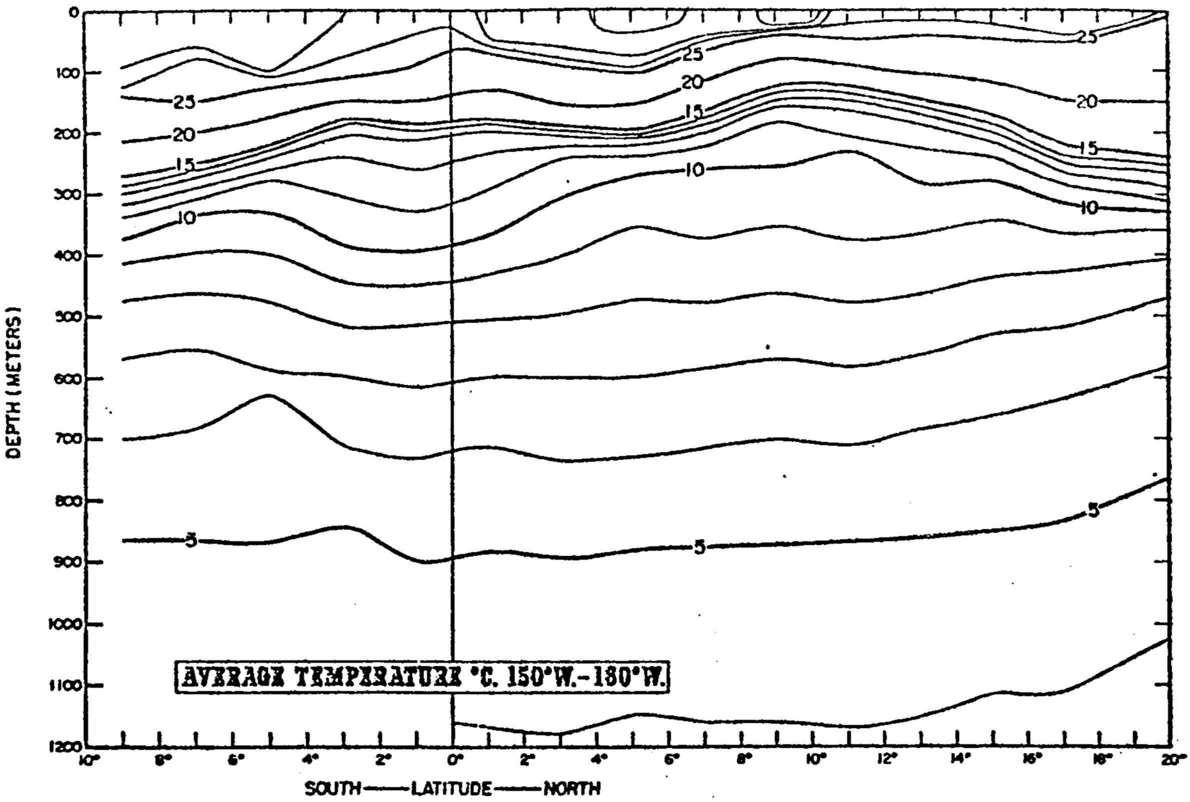


Figure 29.--Schematic representation of the major surface currents and surface isotherms in the central and eastern equatorial Pacific. The area most intensively surveyed is shaded. Arrows denote approximate current direction (adapted from Schott 1935 by Murphy and Shomura 1972).



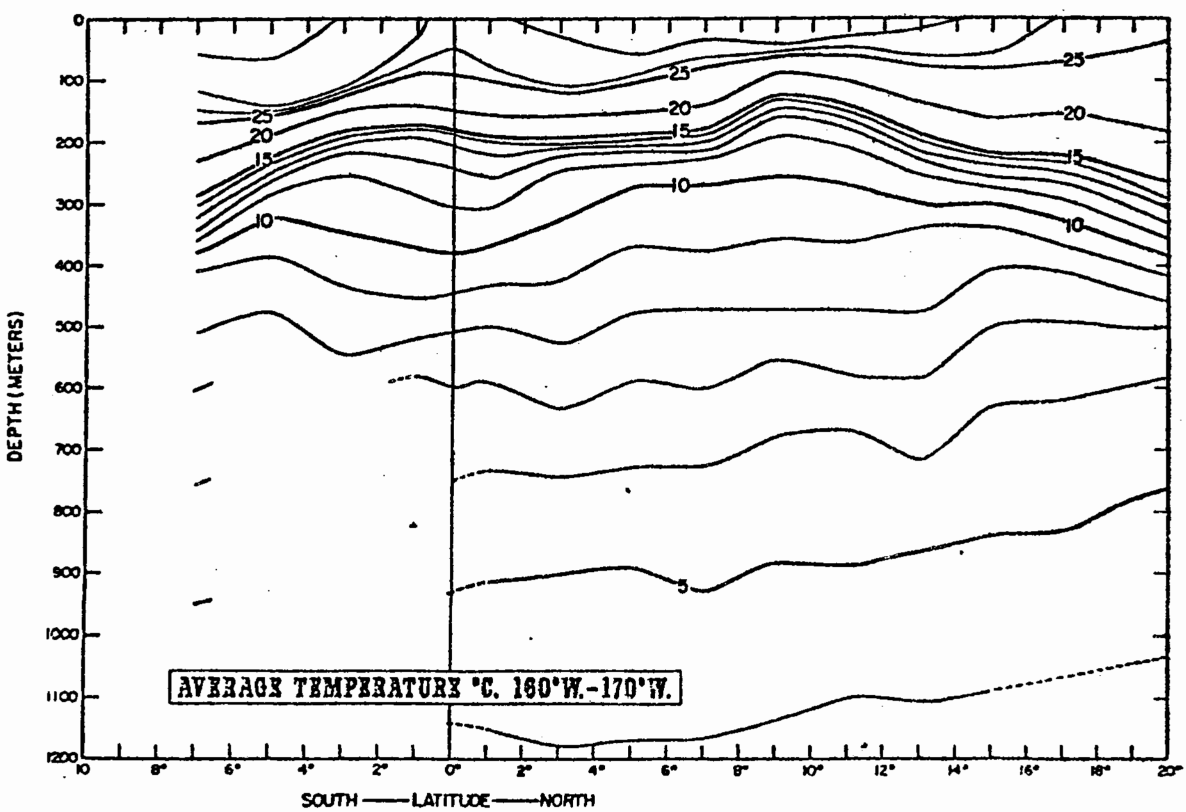


Figure 30.--Meridional temperature sections, based on average values in areas of 2° of latitude by 10° of longitude (from Barkley 1962, see footnote 3).

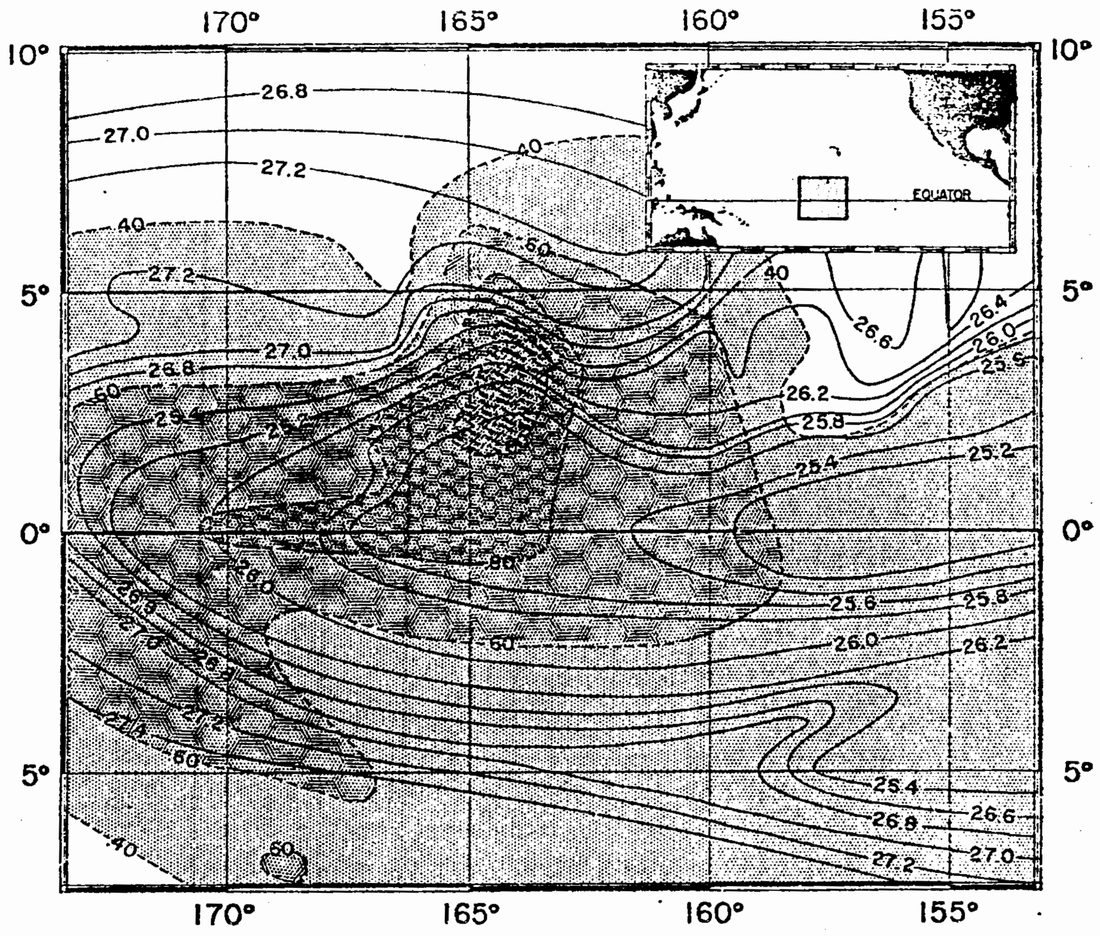


Figure 31.--Surface temperature and variation in phosphate (indicated by shading) in the central equatorial Pacific Ocean (Sette and staff 1954).

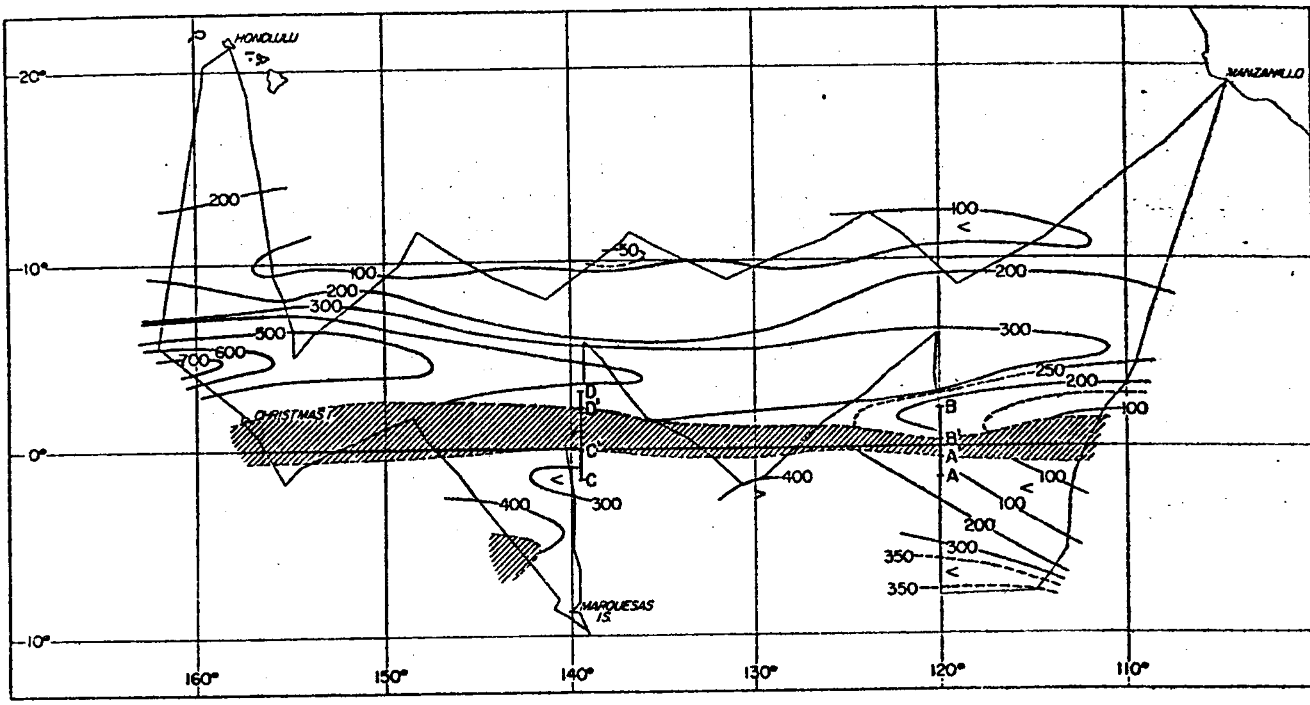


Figure 32.--Depth of the thermocline as determined from the BT
September-December 1955.
data,/ The shaded section is the region where thermocline depth could not be determined objectively, because the BT trace showed either more than one inflection or a continuous negative gradient from the surface to the maximum depth of the trace (from Austin 1960).

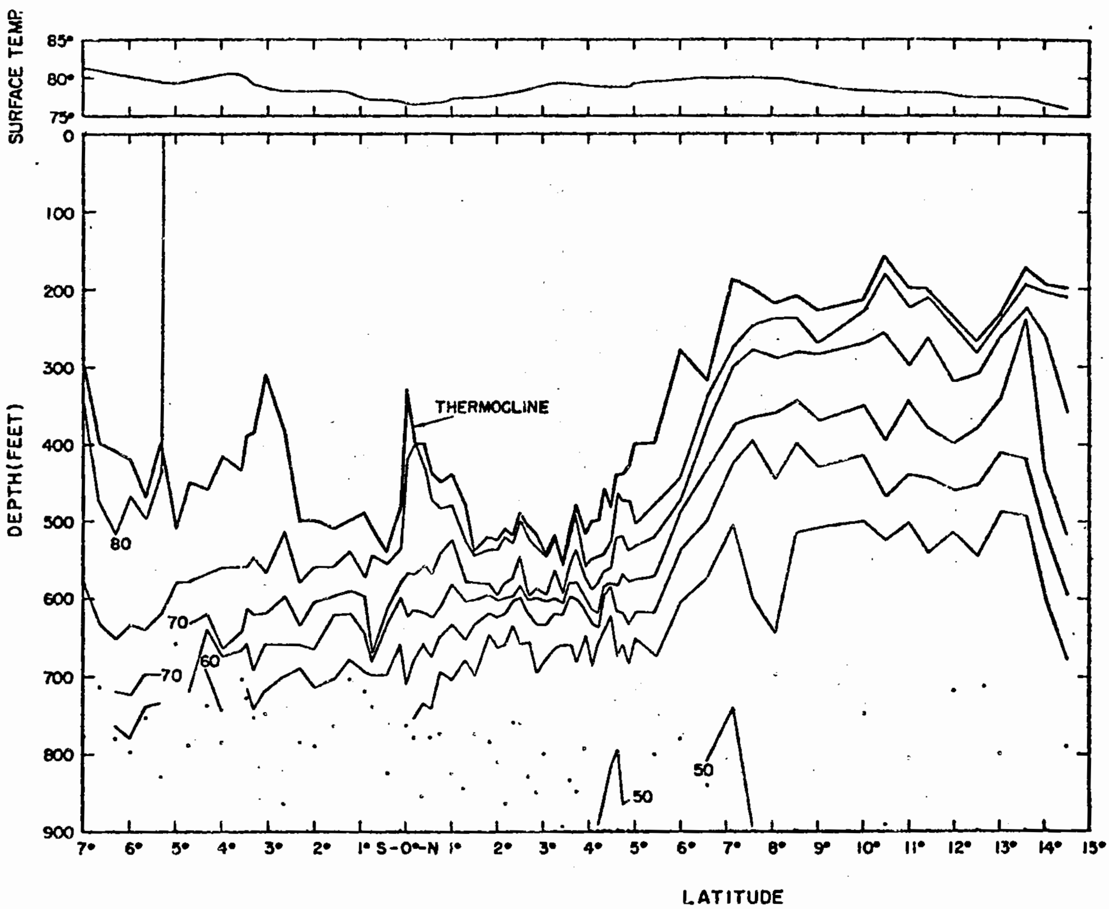


Figure 33.--Above, surface temperature and below, temperature section based on BT data along long. 158°W, 15-26 January 1951. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. *Hugh M. Smith* cruise 8 (from Cromwell 1954).

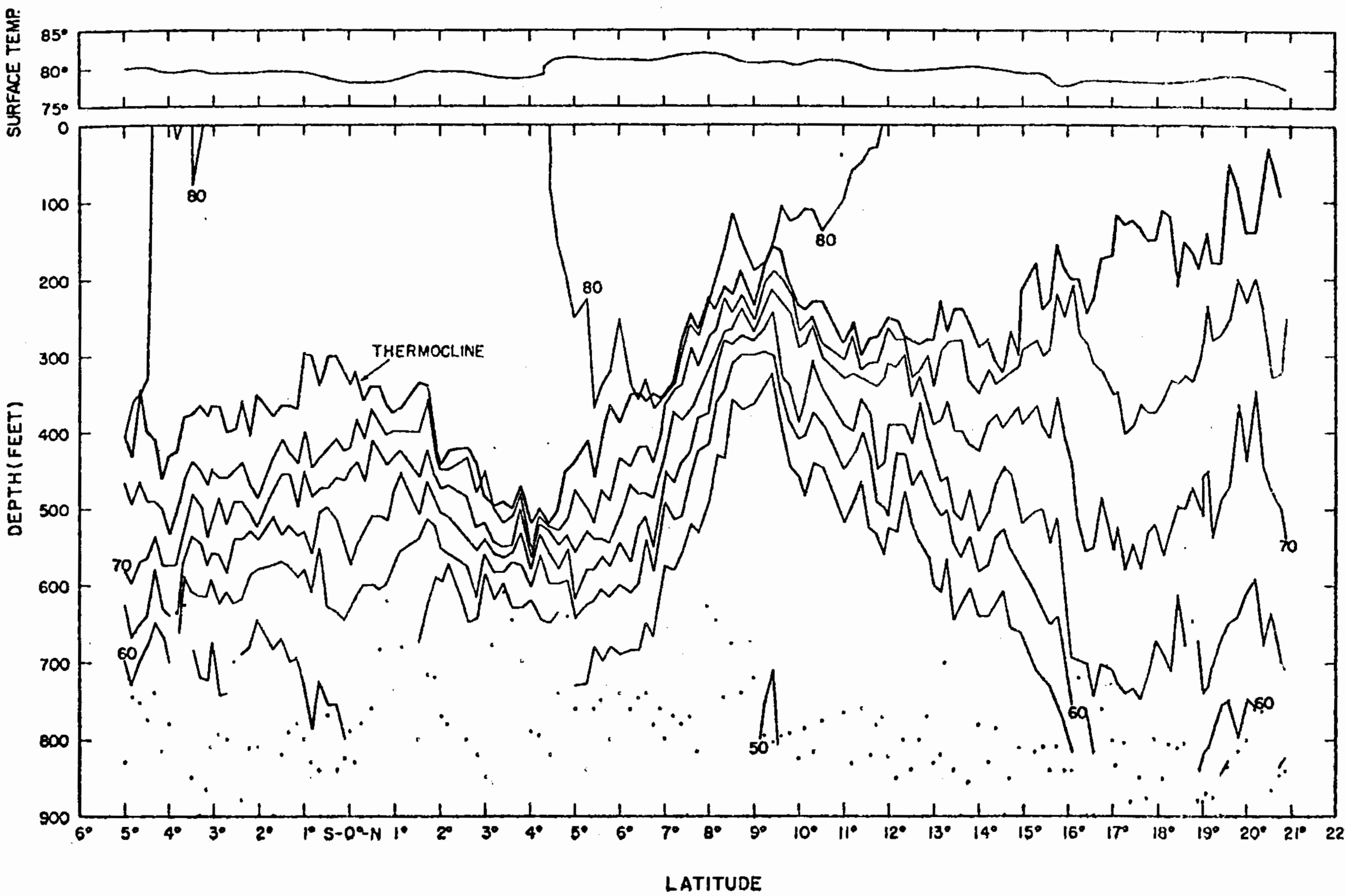


Figure 34.--<u>Above</u>, surface temperature and <u>below</u>, temperature section based on BT data along long. 158°W, 28 July-6 August 1950. Isotherms drawn at intervals of 5°F. Dots indicate depths of observations. <u>Hugh M. Smith</u> cruise 5 (from Cromwell 1954).

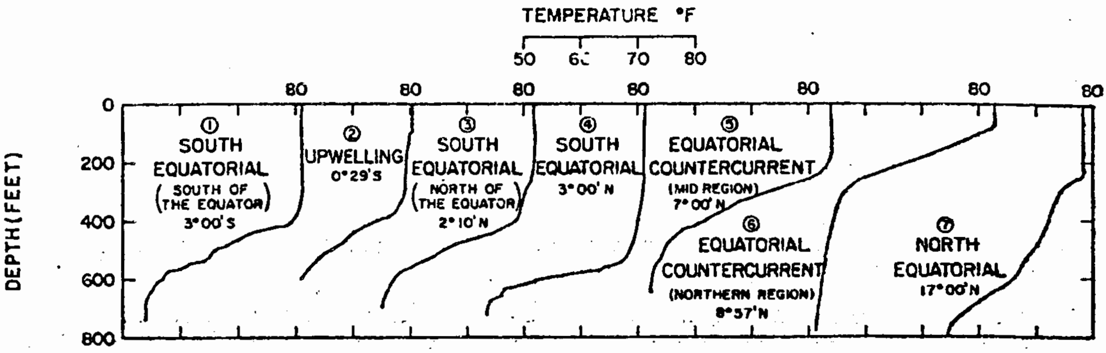


Figure 35.--Typical BT traces for various regions crossed during <u>Hugh M. Smith</u> cruise 11, August-September 1951 (from Austin 1954a).

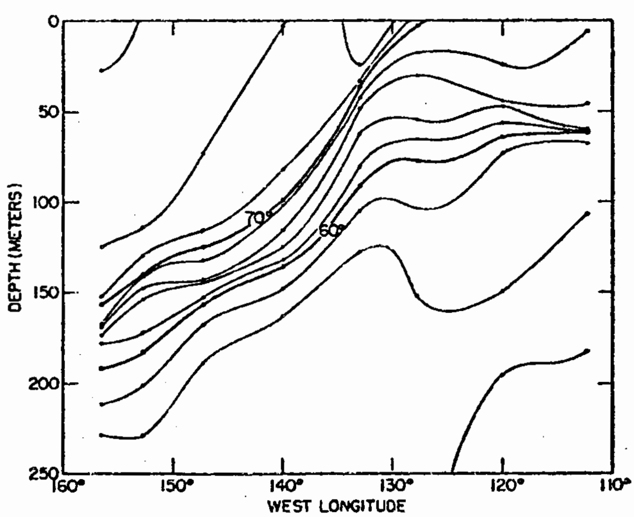


Figure 36.--Vertical temperature (°F) distribution along the equator illustrating the east-west slope of the thermocline, September-December 1955 (from Austin 1960).

JANUARY

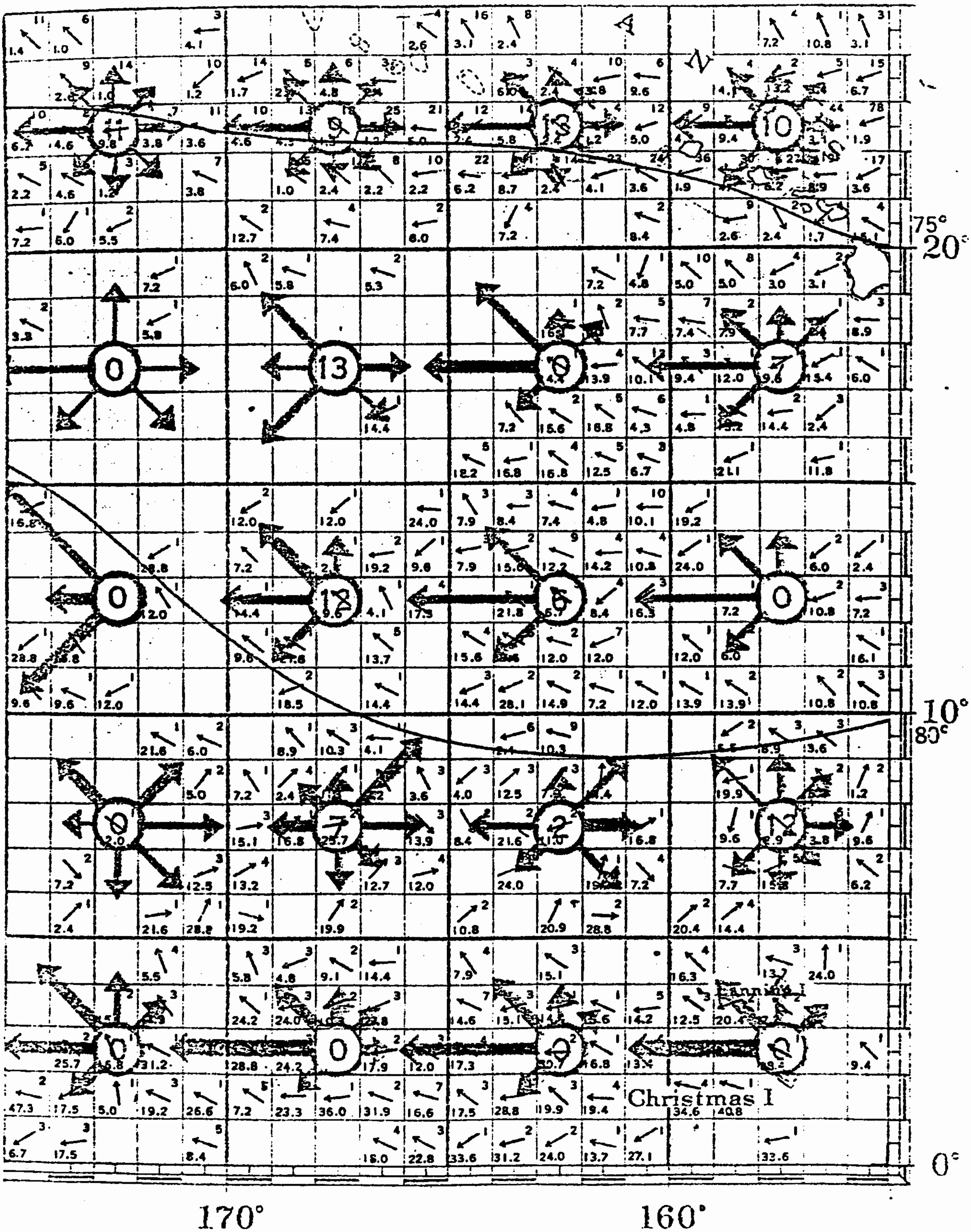


Figure 37a.--Surface drift vectors for January (from U.S. Navy Hydrographic Office 1950).

FEBRUARY

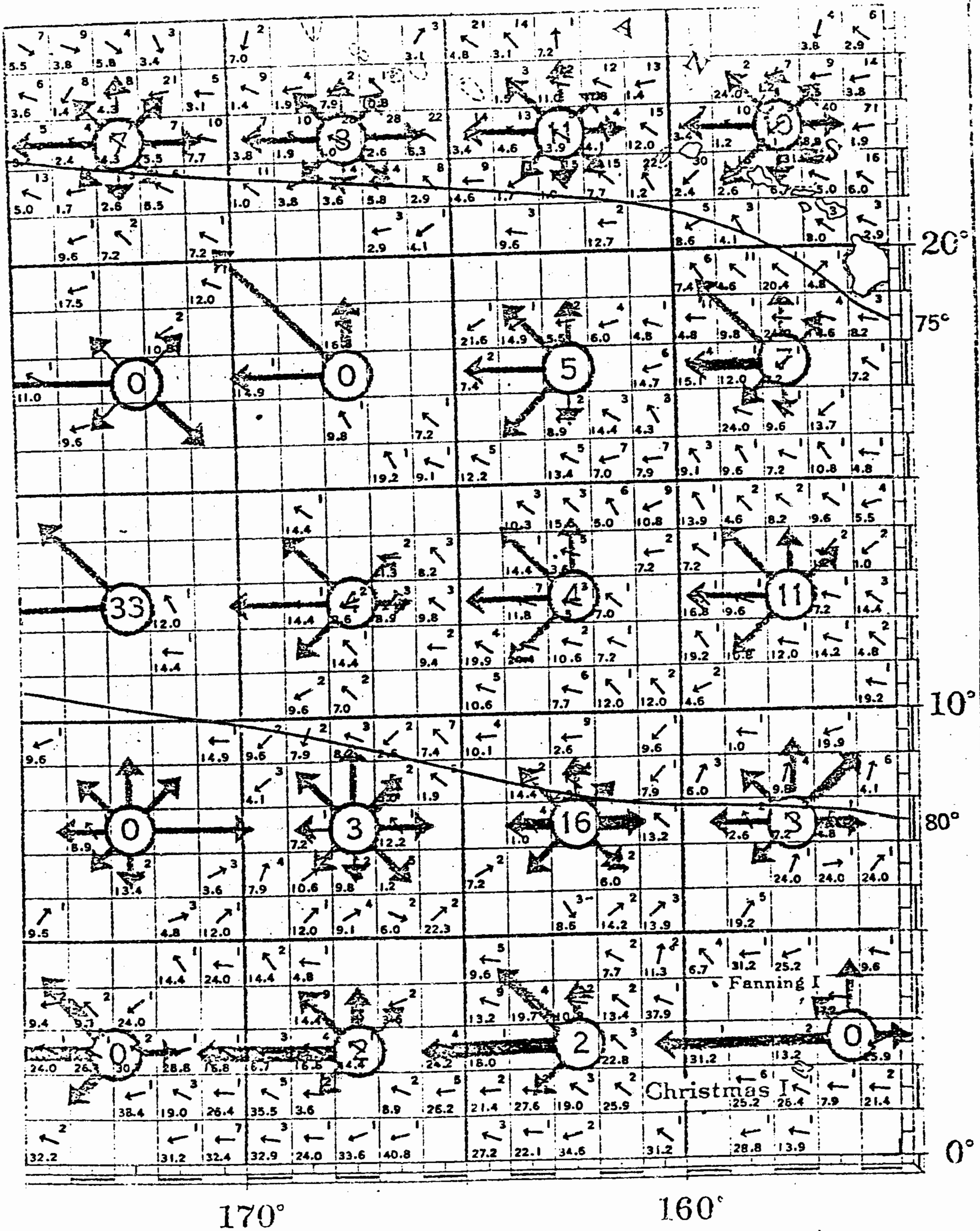


Figure 37b.--Surface drift vectors for February (from U.S. Navy Hydrographic Office 1950).

MARCH

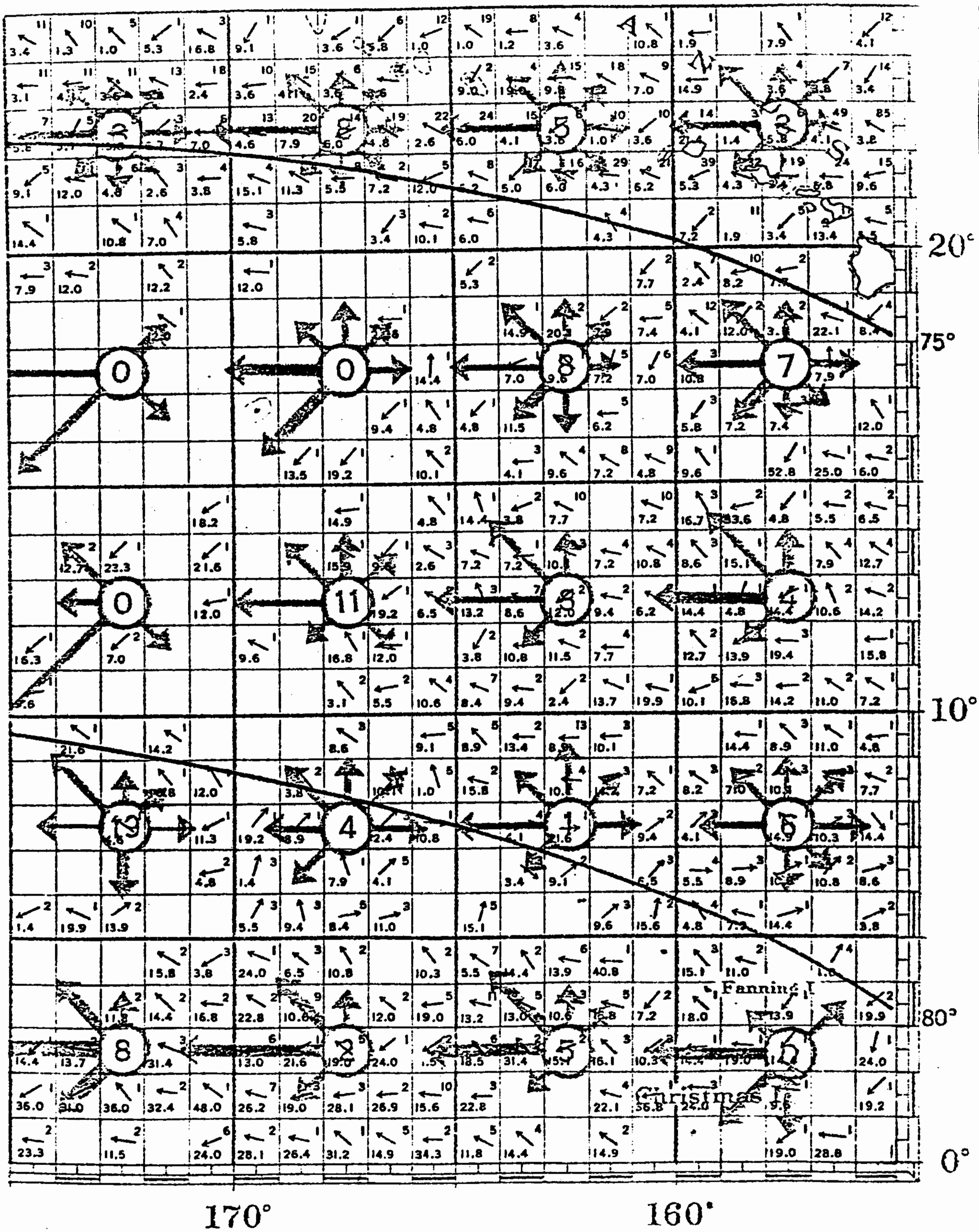


Figure 37c.--Surface drift vectors for March (from U.S. Navy Hydrographic Office 1950).

APRIL

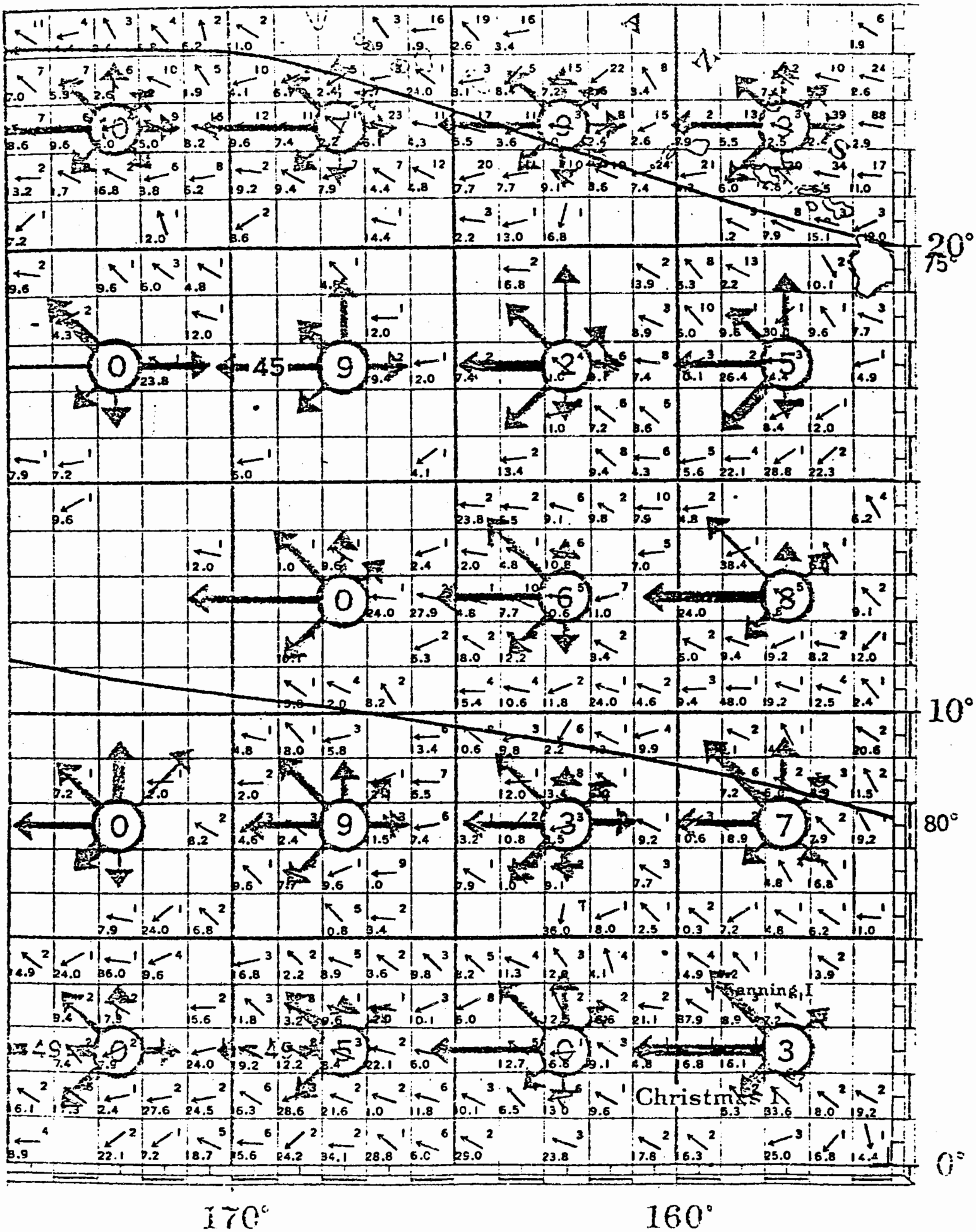


Figure 37d.--Surface drift vectors for April (from U.S. Navy Hydrographic Office 1950).

MAY

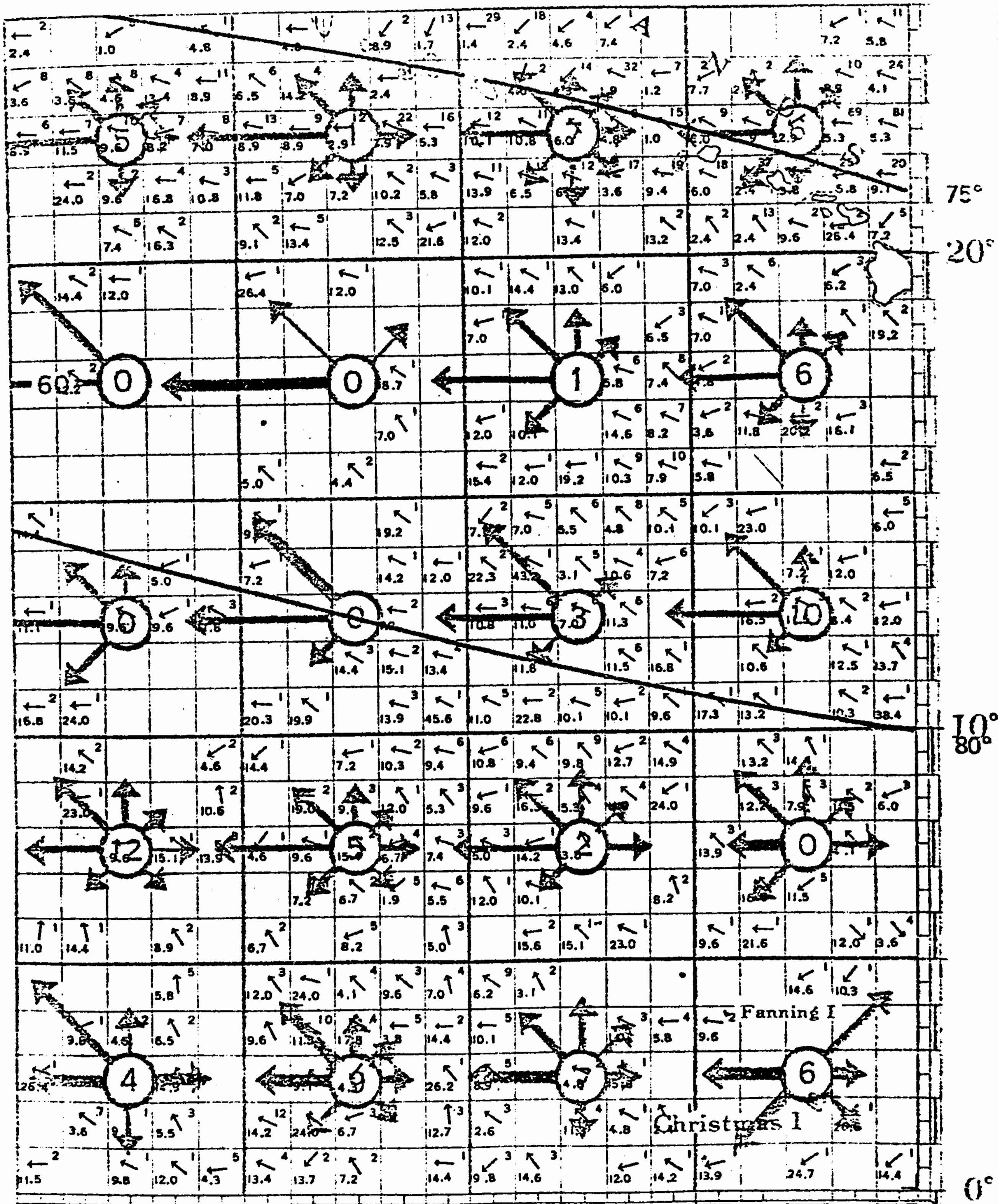


Figure 37e.--Surface drift vectors for May (from U.S. Navy Hydrographic Office 1950).

JUNE

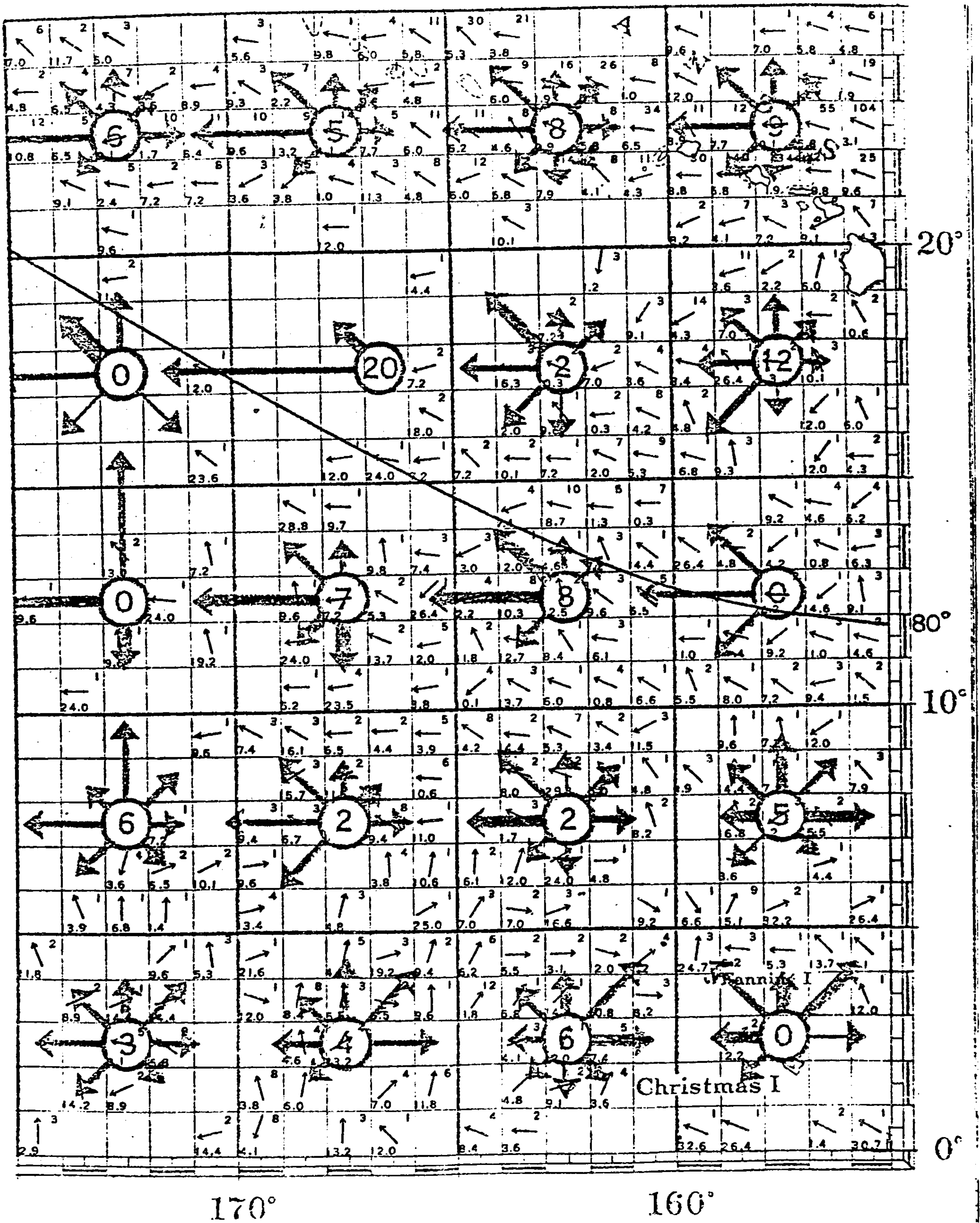


Figure 37f.--Surface drift vectors for June (from U.S. Navy Hydrographic Office 1950).

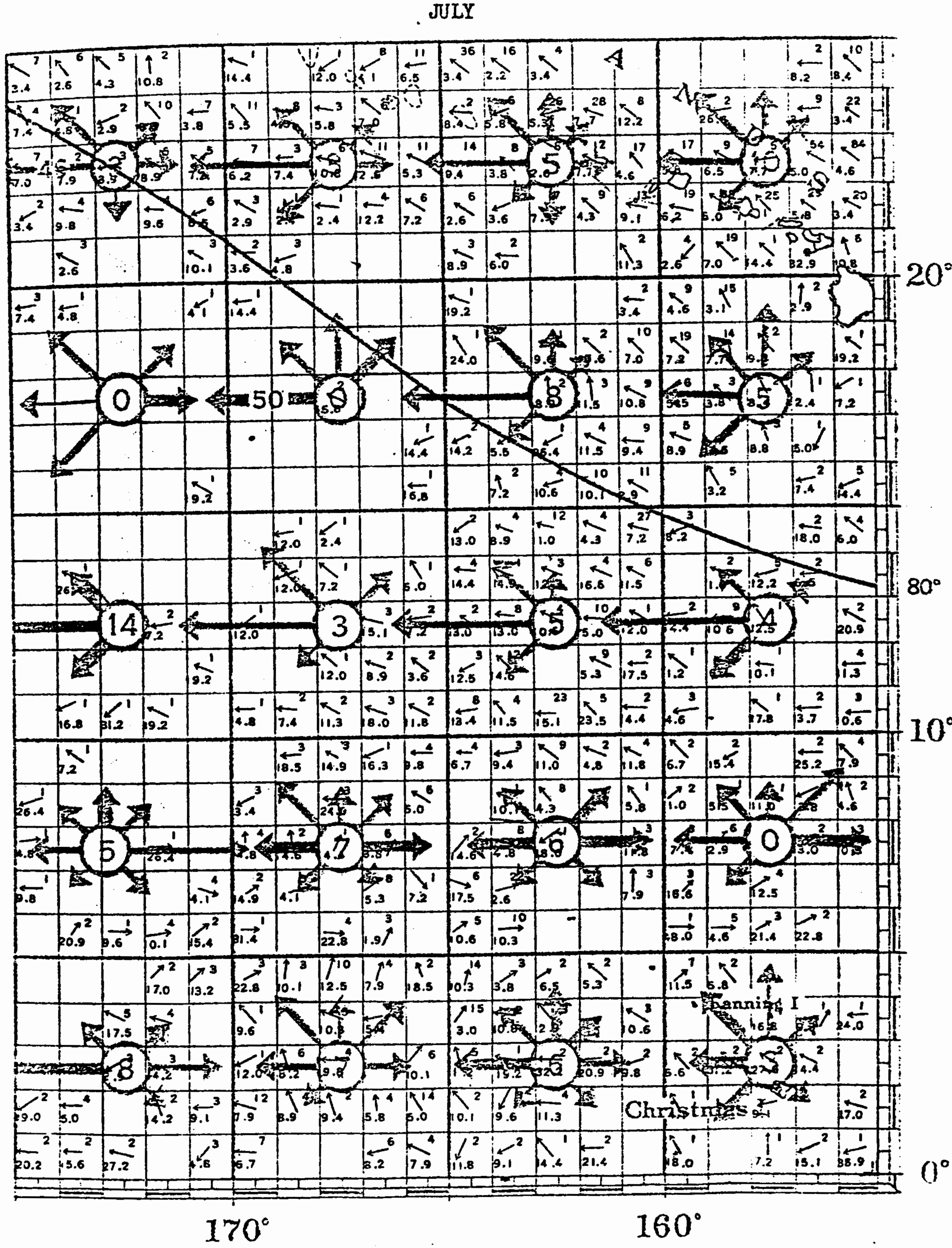


Figure 37g.--Surface drift vectors for July (from U.S. Navy Hydrographic Office 1950).

AUGUST

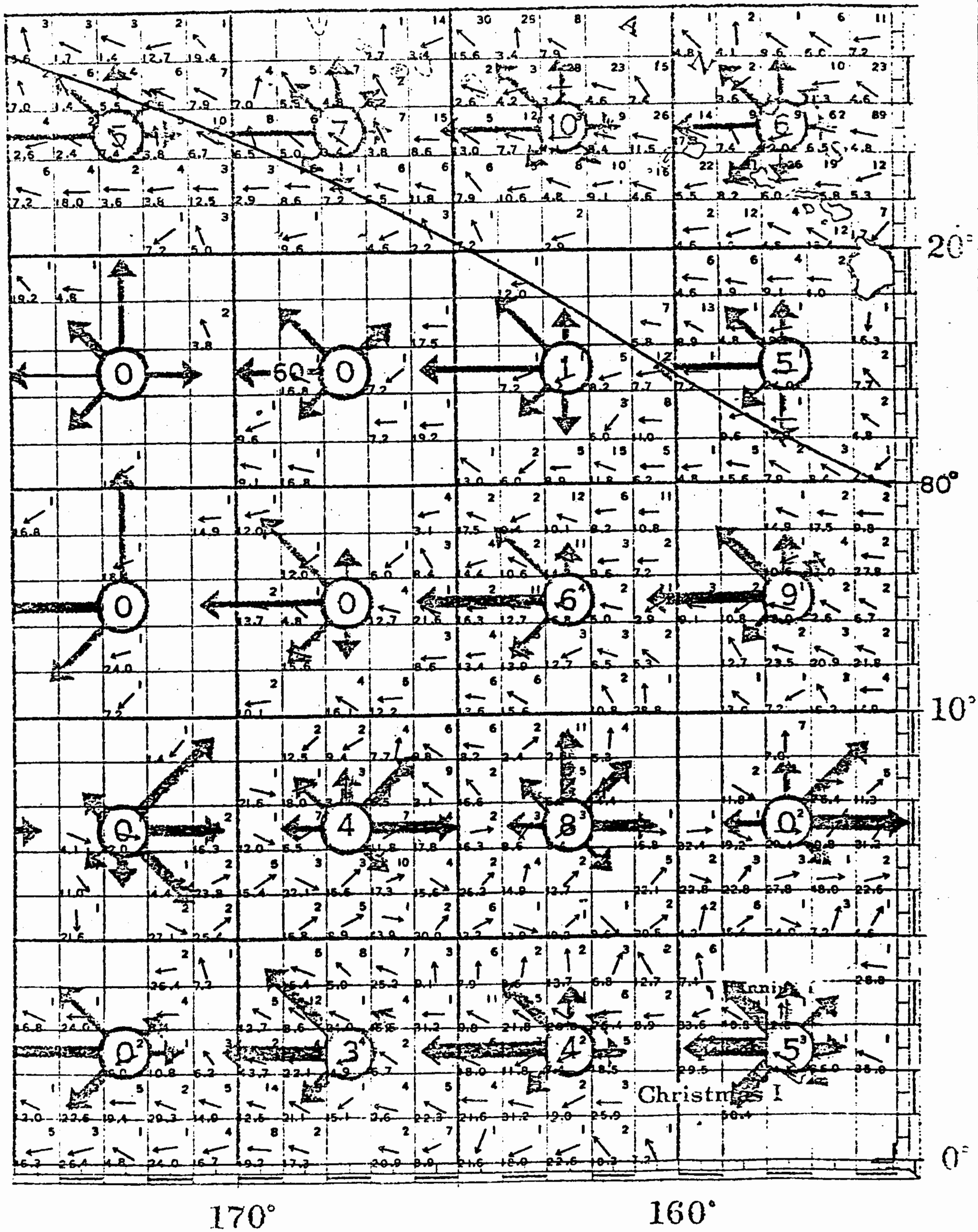


Figure 37h.--Surface drift vectors for August (from U.S. Navy Hydrographic Office 1950).

SEPTEMBER

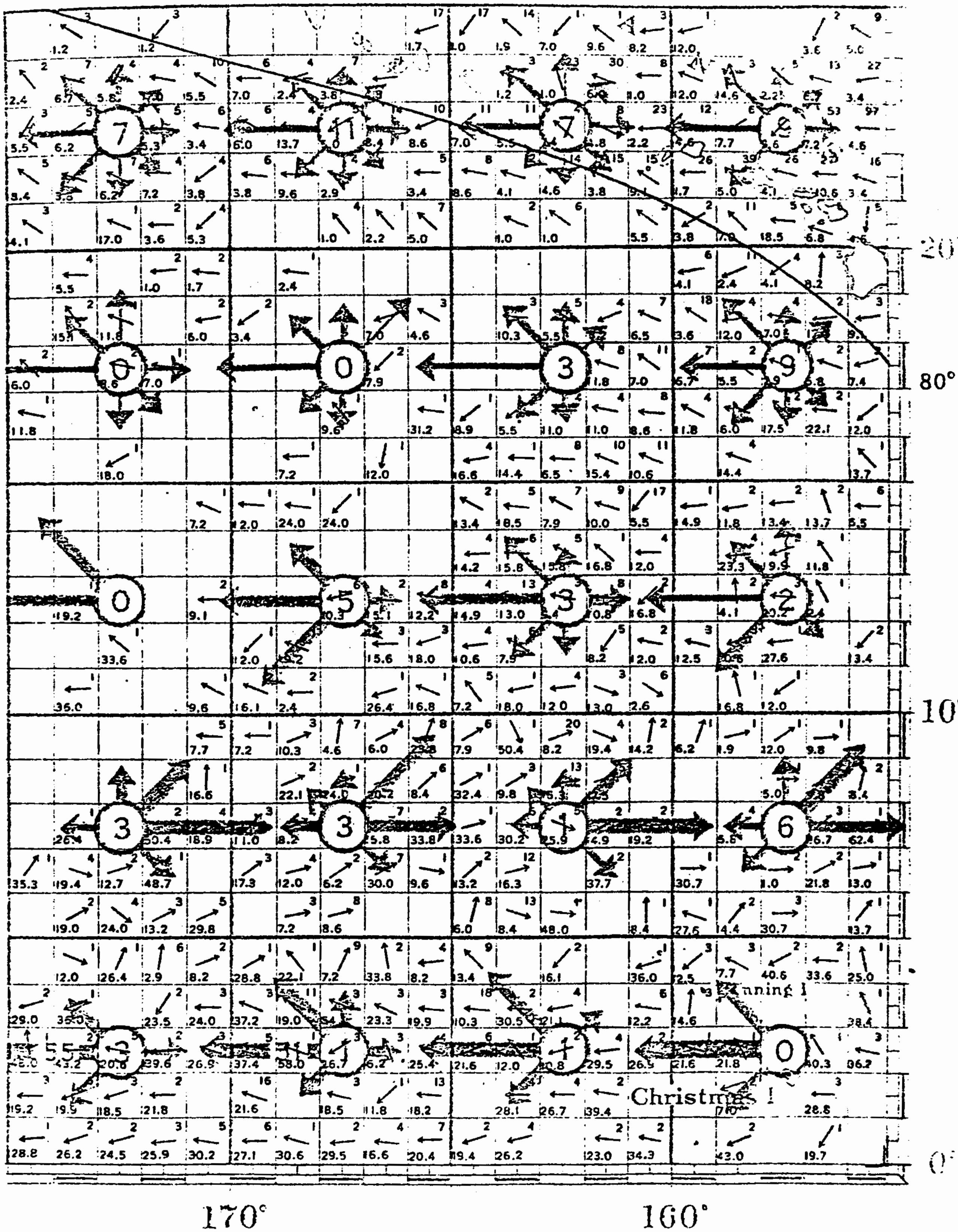


Figure 37i.--Surface drift vectors for September (from U.S. Navy Hydrographic Office 1950).

OCTOBER

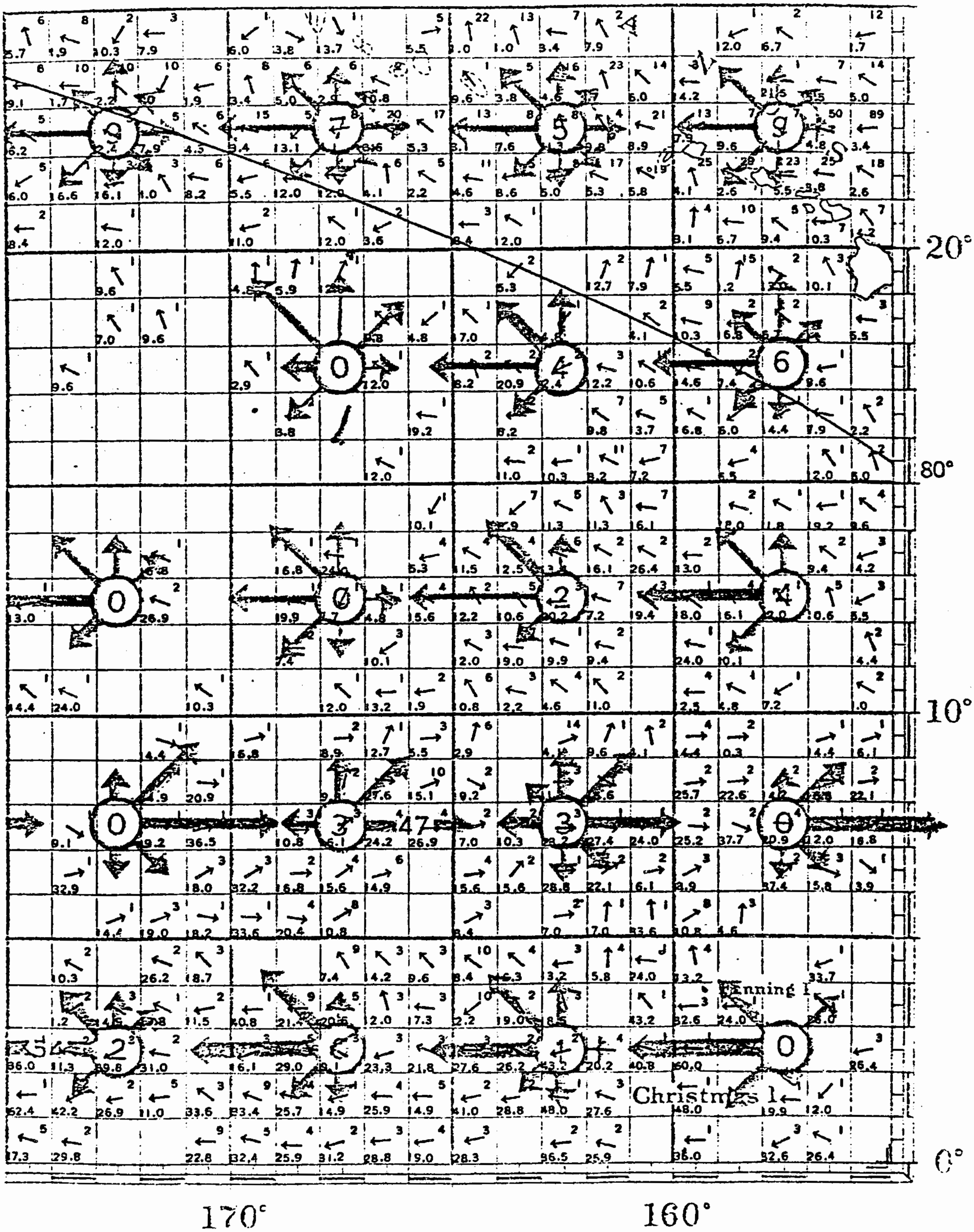


Figure 37j.--Surface drift vectors for October (from U.S. Navy Hydrographic Office 1950).

NOVEMBER

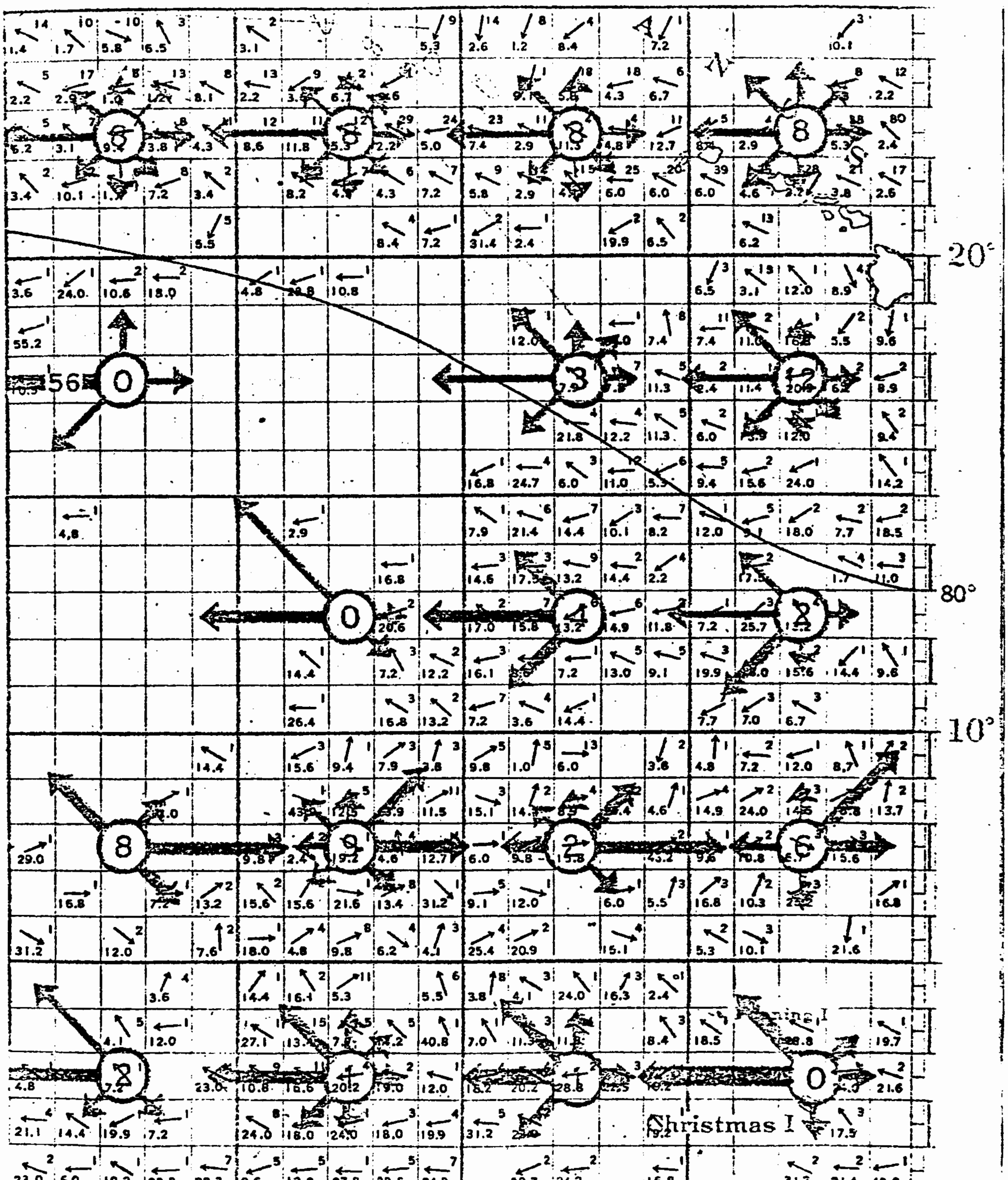


Figure 37k.--Surface drift vectors for November (from U.S. Navy Hydrographic Office 1950).

DECEMBER

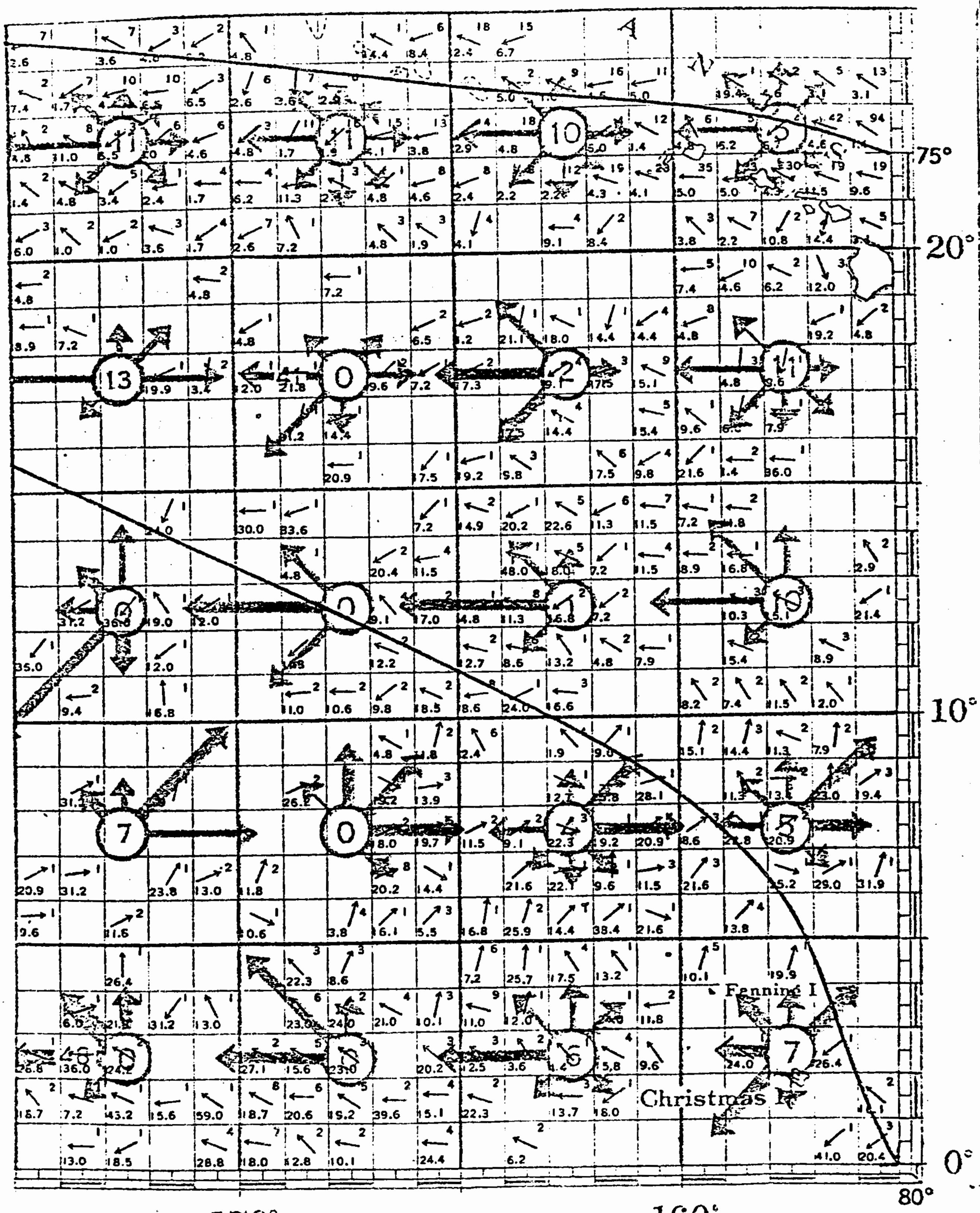


Figure 37ℓ.--Surface drift vectors for December (from U.S. Navy Hydrographic Office 1950).

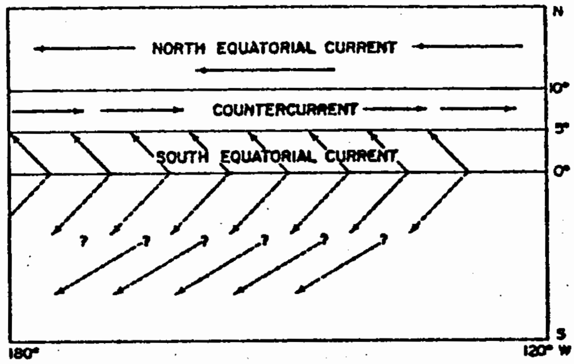


Figure 38.--Schematic view of the equatorial current system incorporating recent empirical determinations of flow north of the equator. Flow south of the equator is indicated as questionable (from Murphy and Shomura 1972).

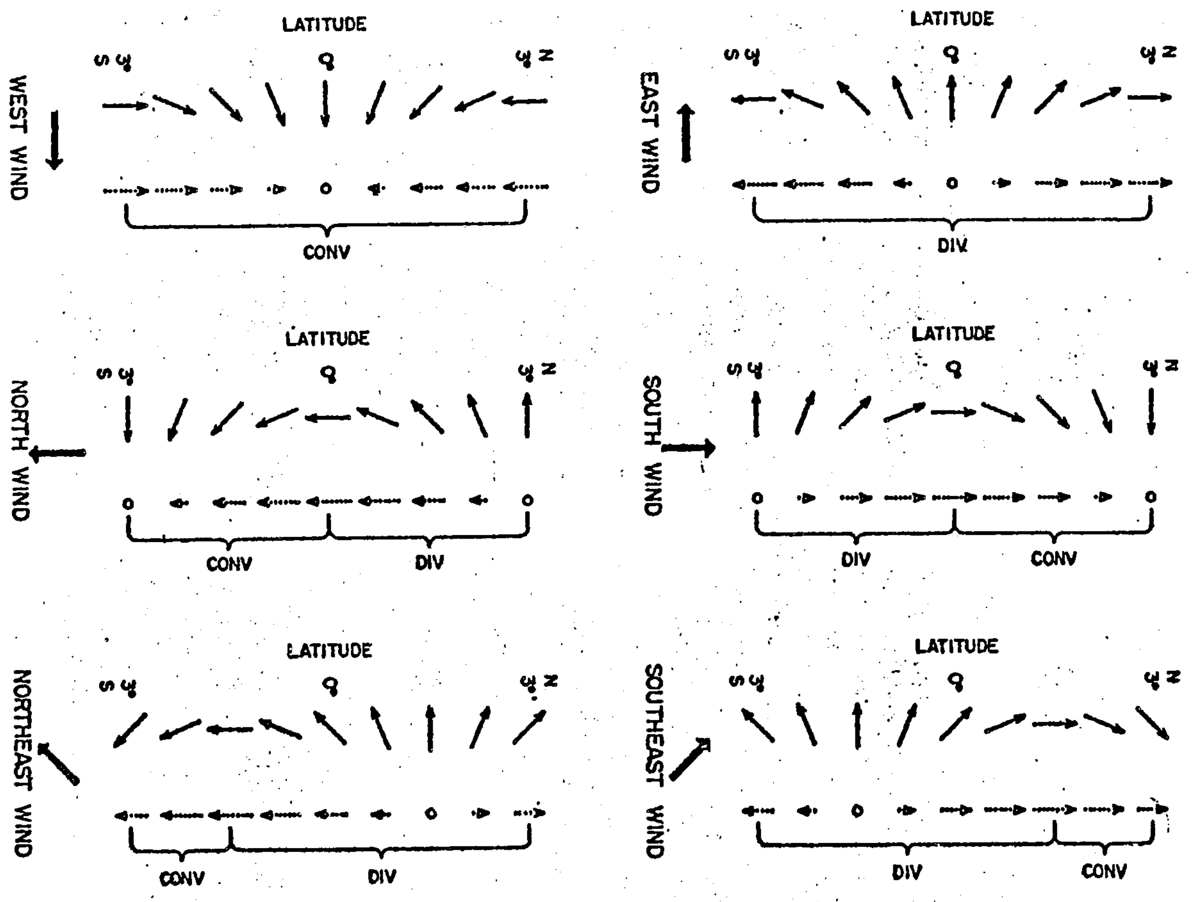


Figure 39.--Directions of current transport (solid arrows) which would exist near the equator under various wind conditions if there were no pressure-gradient force acting. The current magnitude is drawn everywhere constant (solid arrows). For each wind condition the meridional components of the current transport (dotted arrows) are drawn to emphasize the regions of meridional divergence (Div.) and convergence (Conv.) (from Cromwell 1953).

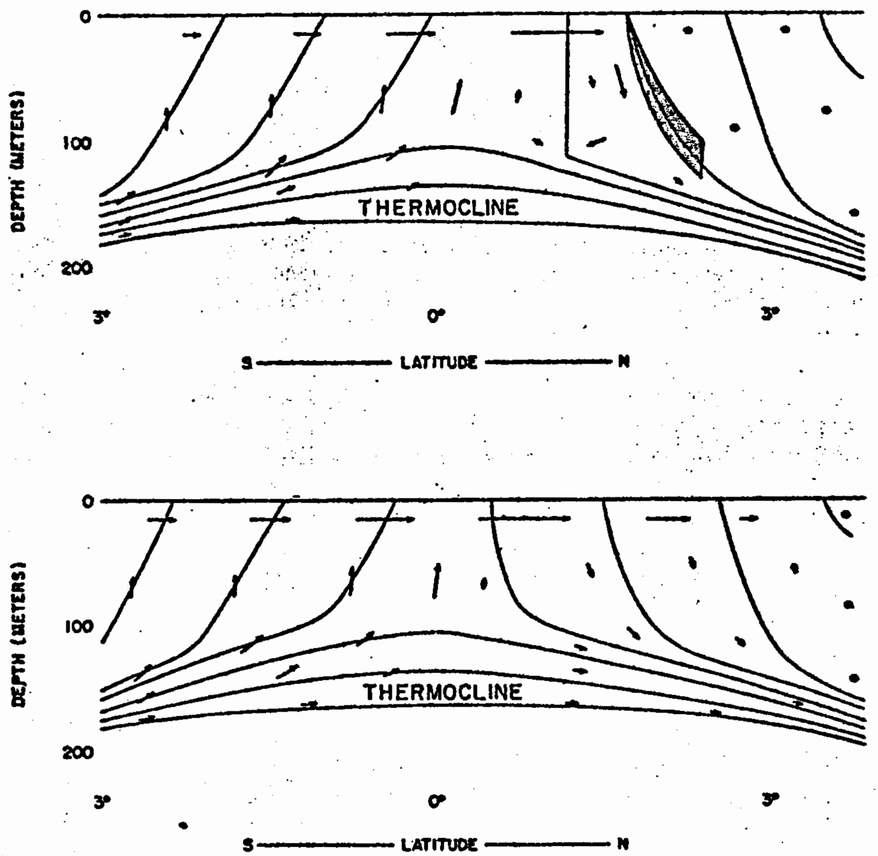


Figure 40.--Schematic representation of circulation in the meridional plane near the equator during a southeast wind when front is present (below). The arrows have the character of streamlines and do not represent trajectories. The arrow shaft lengths indicate roughly the relative magnitudes of flow. Small circles indicate regions of slight and variable flow in this plane. The shaded zone in the upper diagram represents an equatorial front (Cromwell 1953).

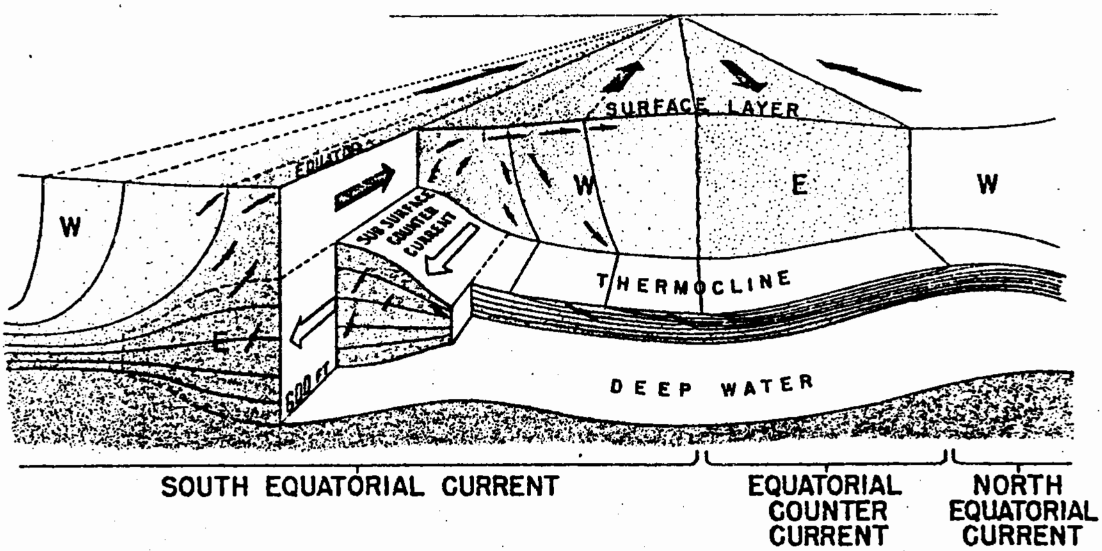


Figure 41.--Concept of equatorial circulation along long. 150°W. The surface currents are shown by broad arrows; the vertical temperature structure by the fine lines of equal temperature (from Sette and staff 1954).

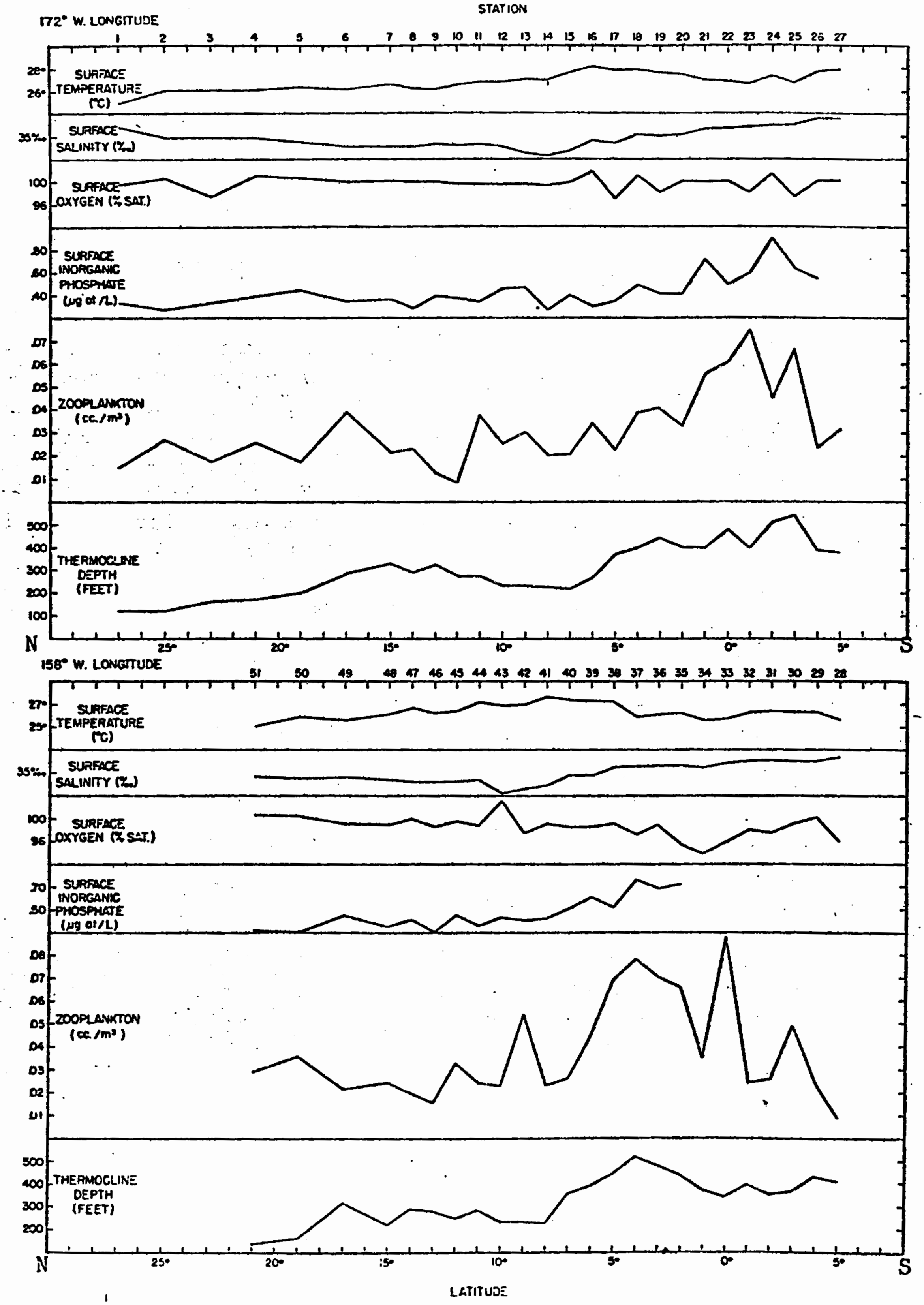


Figure 42.--Variations in temperature, salinity, oxygen, inorganic phosphate, thermocline depth, and zooplankton volume along long. 158° and 172°W as found on <u>Hugh M. Smith</u> cruise 5, June-August 1950 (from King and Demond 1953).

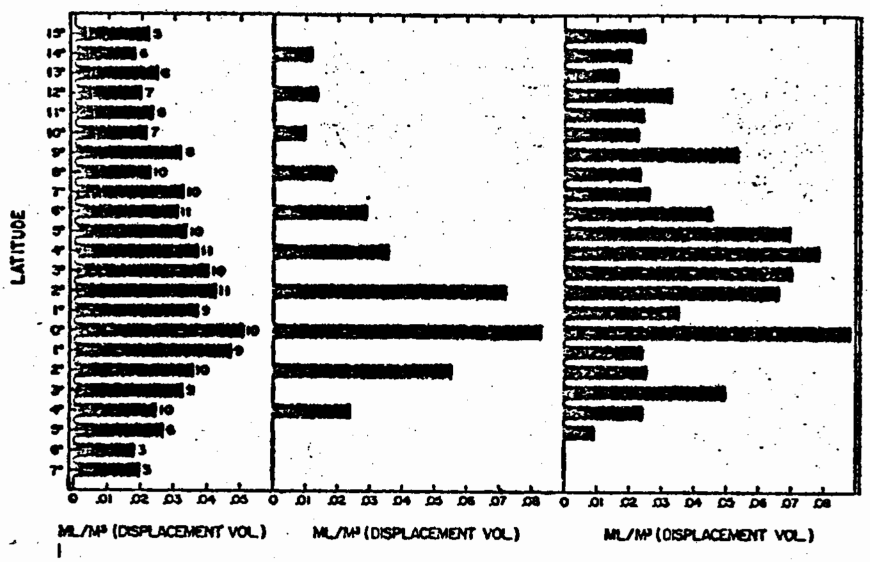


Figure 43.--Left: Zooplankton data from 11 crossings of the equatorial currents between long. 140°W and 180°, combined grossly without regard for longitude or season. The number of observations included in the averaging for each degree of latitude appear at the right. Middle and right: Zooplankton data concurrent with the hydrographic sections examined by Cromwell (1953).

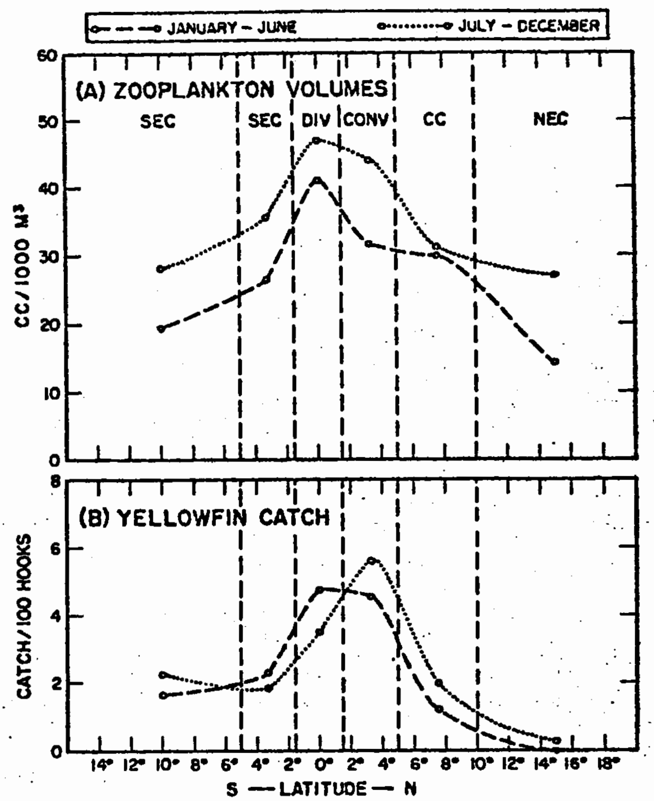


Figure 44.--Variation with the current system in (A) zooplankton volumes (adjusted) and (B) yellowfin tuna longline catch for the two 6-month periods, January-June, a period with northeast or light and variable winds, and July-December, a period of prevailing southeast trade winds (in the central equatorial Pacific Ocean) (from King and Hida 1957).

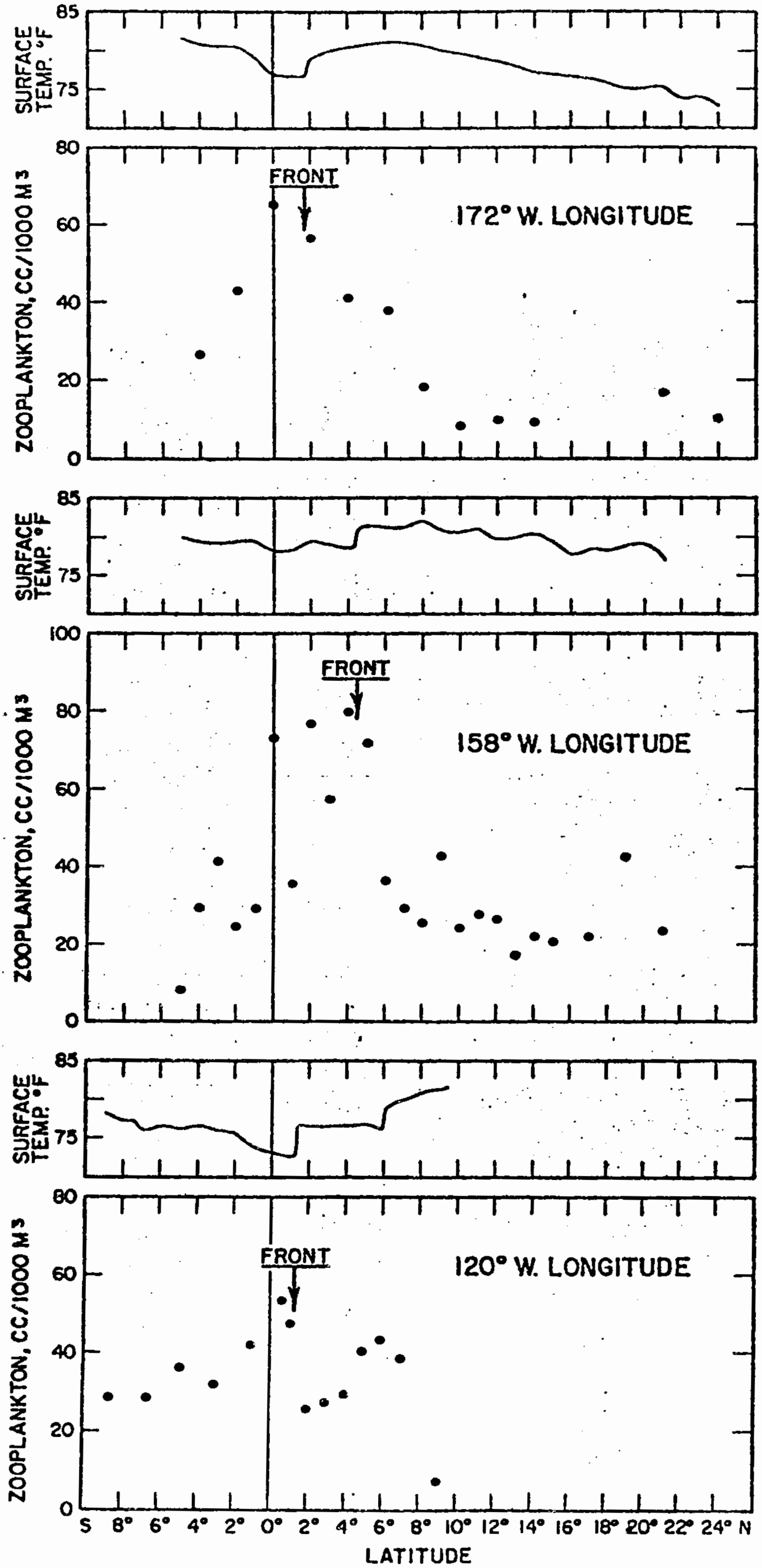


Figure 45.--Relation of an oceanographic front to the distribution of zooplankton (adjusted volumes) as demonstrated by three series of stations along long. 172°, 158°, and 120°W of Hugh M. Smith cruises 2, 5, and 18, respectively (from King and Hida 1957).

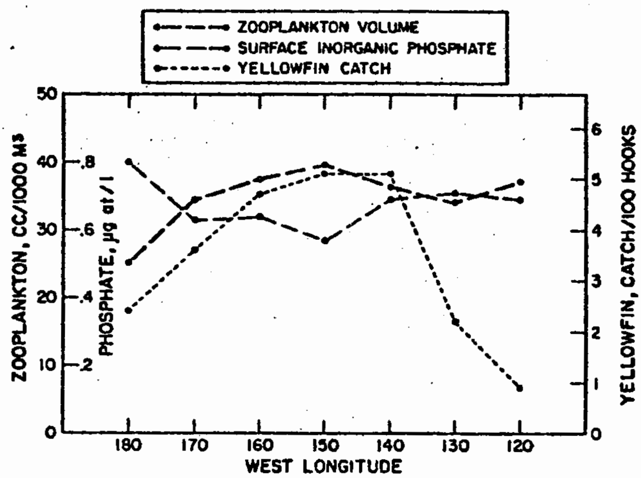


Figure 46.--Longitudinal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent, at about lat. 5°N to 5°S, with the data segregated by 10° intervals of longitude (from King and Hida 1957).

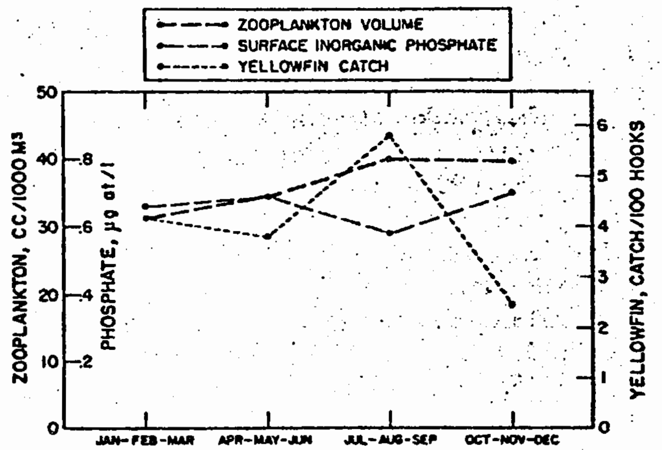
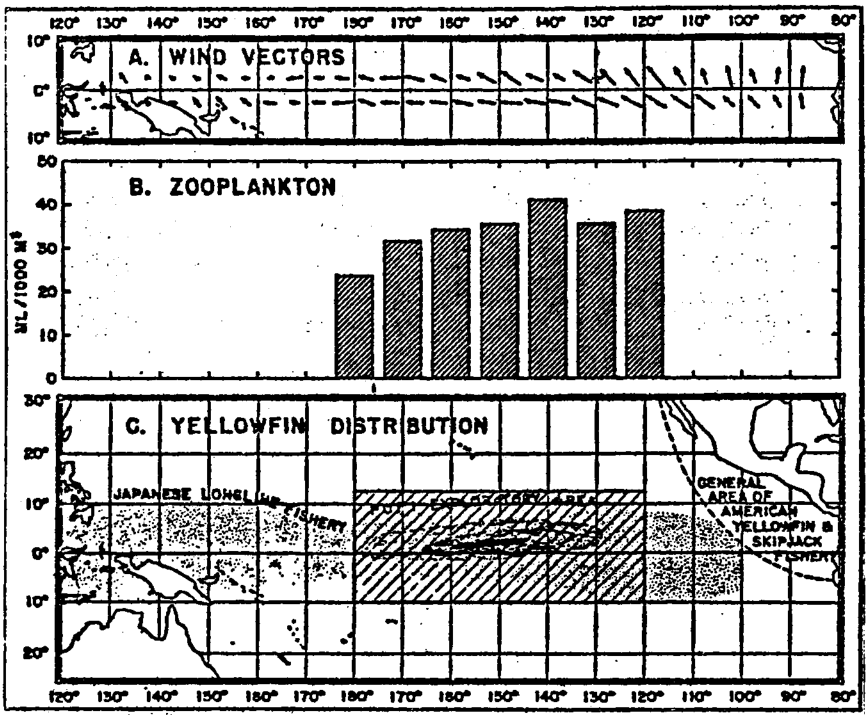


Figure 47.--Seasonal variations in yellowfin tuna longline catch, zooplankton volumes (adjusted) and surface inorganic phosphate for the South Equatorial Current from the southern boundary of the countercurrent at about lat. 5°N to 5°S, with the data segregated into quarterly periods of 3 months each (from King and Hida 1957).

Figure 48.--Wind, plankton, and tuna distribution in the equatorial zone. A. Resultant wind vectors were computed as the weighted means of frequency and speed from the several compass points for 5° squares bordering the equator as published in the U.S. Hydrographic Office Pilot Chart for the North Pacific for August 1952; the arrows point in the direction of travel and their shafts are proportional to the weighted mean speed. B. Mean plankton volumes at several longitudes were computed as the mean of all hauls taken between lat. 5°S and 10°N at or near the given longitude. C. Distribution of yellowfin tuna in the mid-Pacific equatorial region is estimated from longline catches. The light stippling in the POFI area represents less than three yellowfin tuna per hundred hooks, the heaviest represents more than nine per hundred hooks, and the intermediate stippling represents intermediate catching rates. For orientation as to location and area, the extensive band of light stippling represents the area of the Japanese prewar longline fishery; the dashed outline shows the area of the American west coast live bait and purse seine fishery for yellowfin tuna and skipjack tuna. Since preparation of the above chart, a line of fishing stations along long. 110°W has proved the continuity of the band of yellowfin tuna across the "unexplored area" (from Sette 1955).


A. WIND VECTORS
B. ZOOPLANKTON
ML/1000 M³
C. YELLOWFIN DISTRIBUTION
JAPANESE LONGLINE FISHERY
GENERAL AREA OF AMERICAN YELLOWFIN & SKIPJACK FISHERY

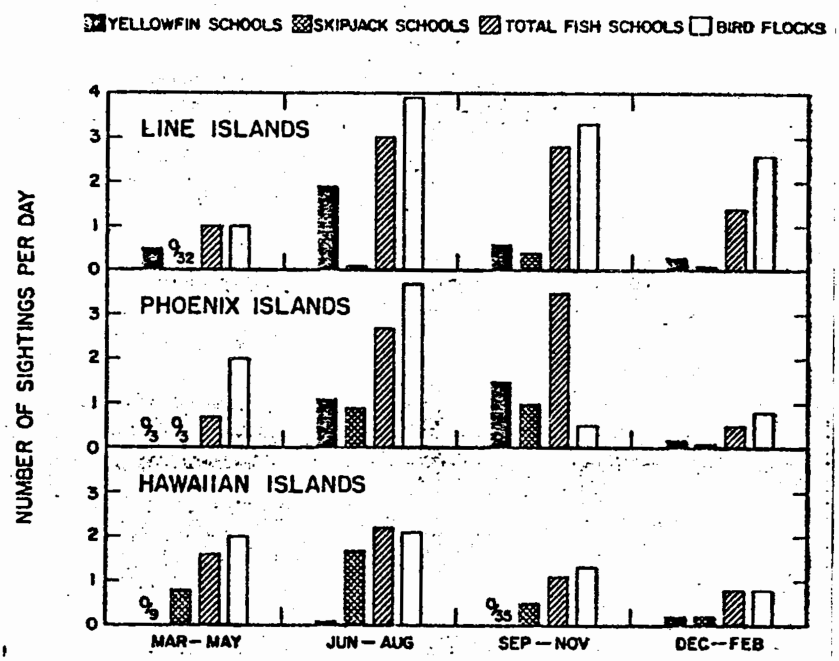


Figure 49.--Seasonal distribution of tuna school sightings in the Line, Phoenix, and Hawaiian Islands. Total fish schools per day include unidentified schools as well as yellowfin tuna and skipjack tuna. The numbers, such as 0/32, indicate that no schools were seen in 32 days of scouting (from Murphy and Ikehara 1955).

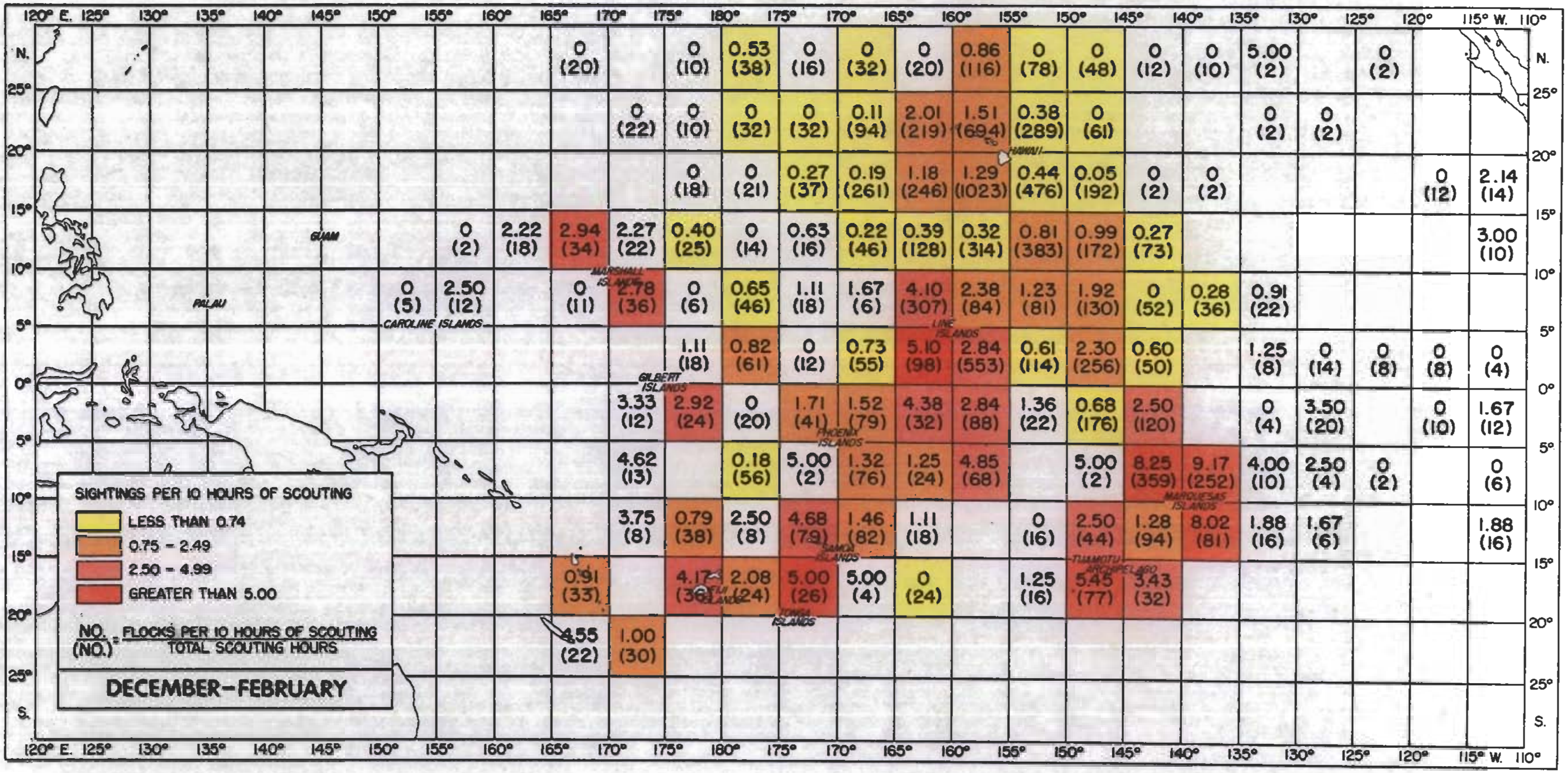


Figure 50a.--Bird flock sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

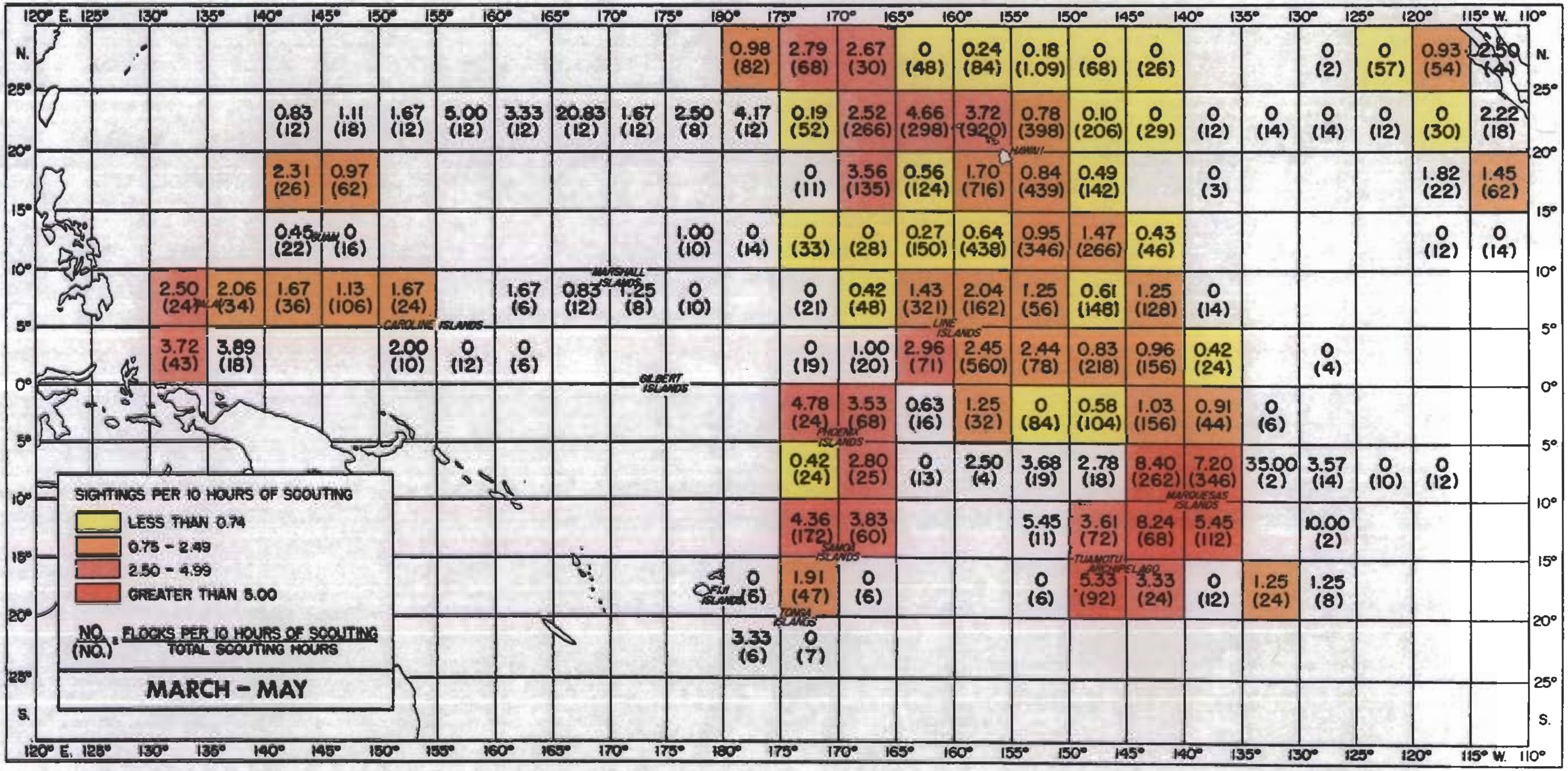


Figure 50b.--Bird flock sightings by National Marine Fisheries Service vessels, March-May 1950-72

(from Naughton, see footnote 5).

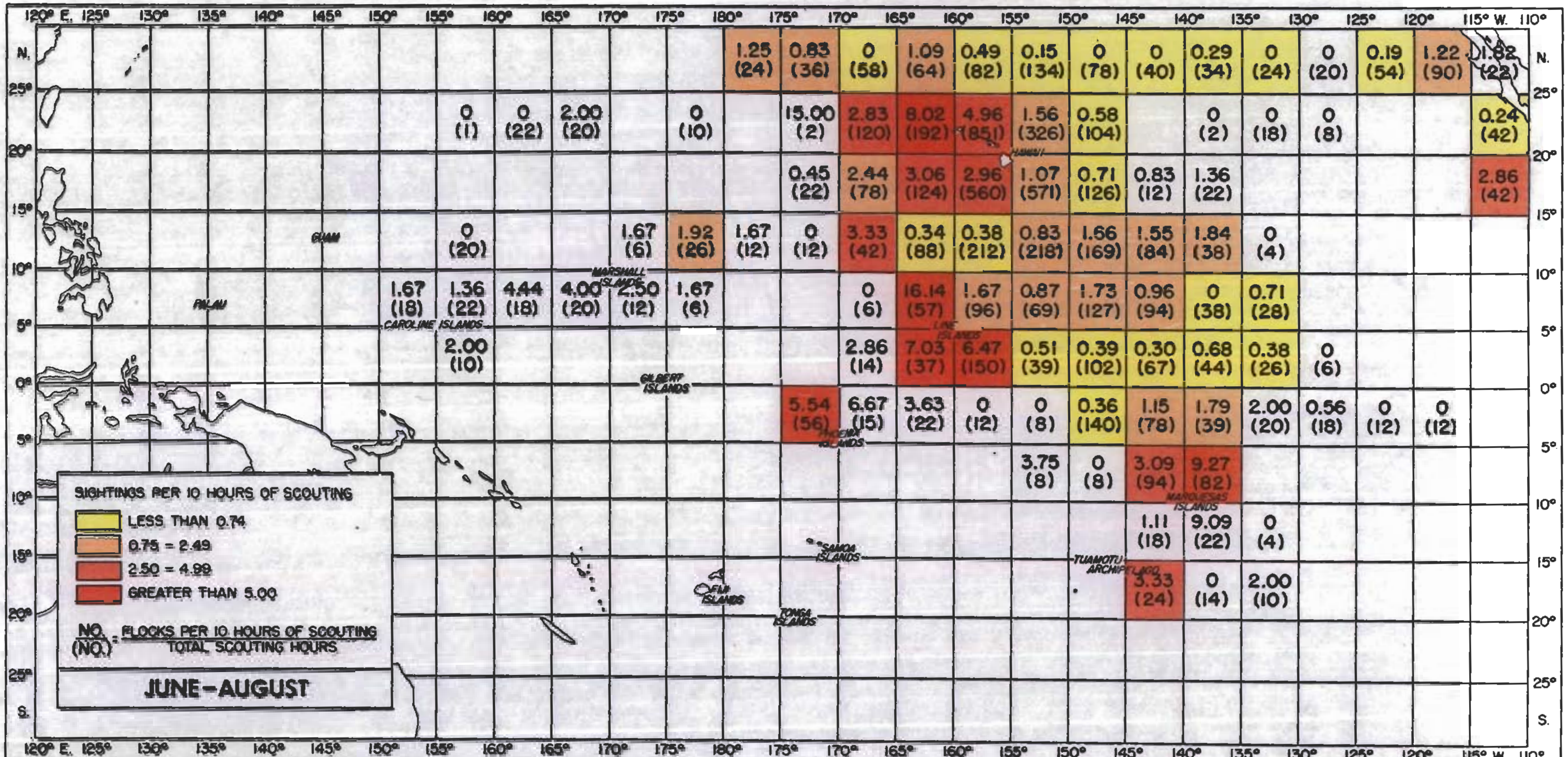


Figure 50c.--Bird flock sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

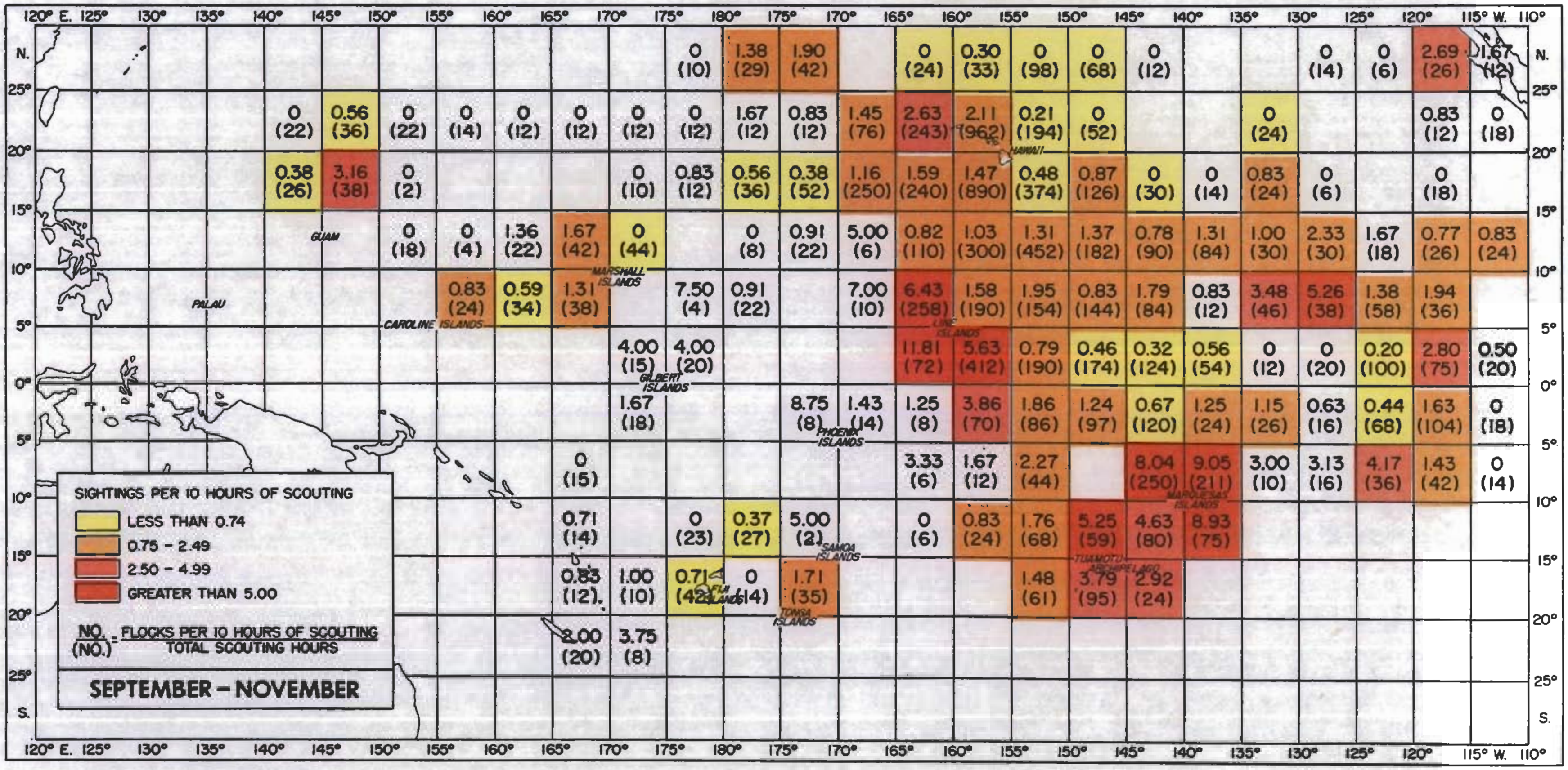


Figure 50d.--Bird flock sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

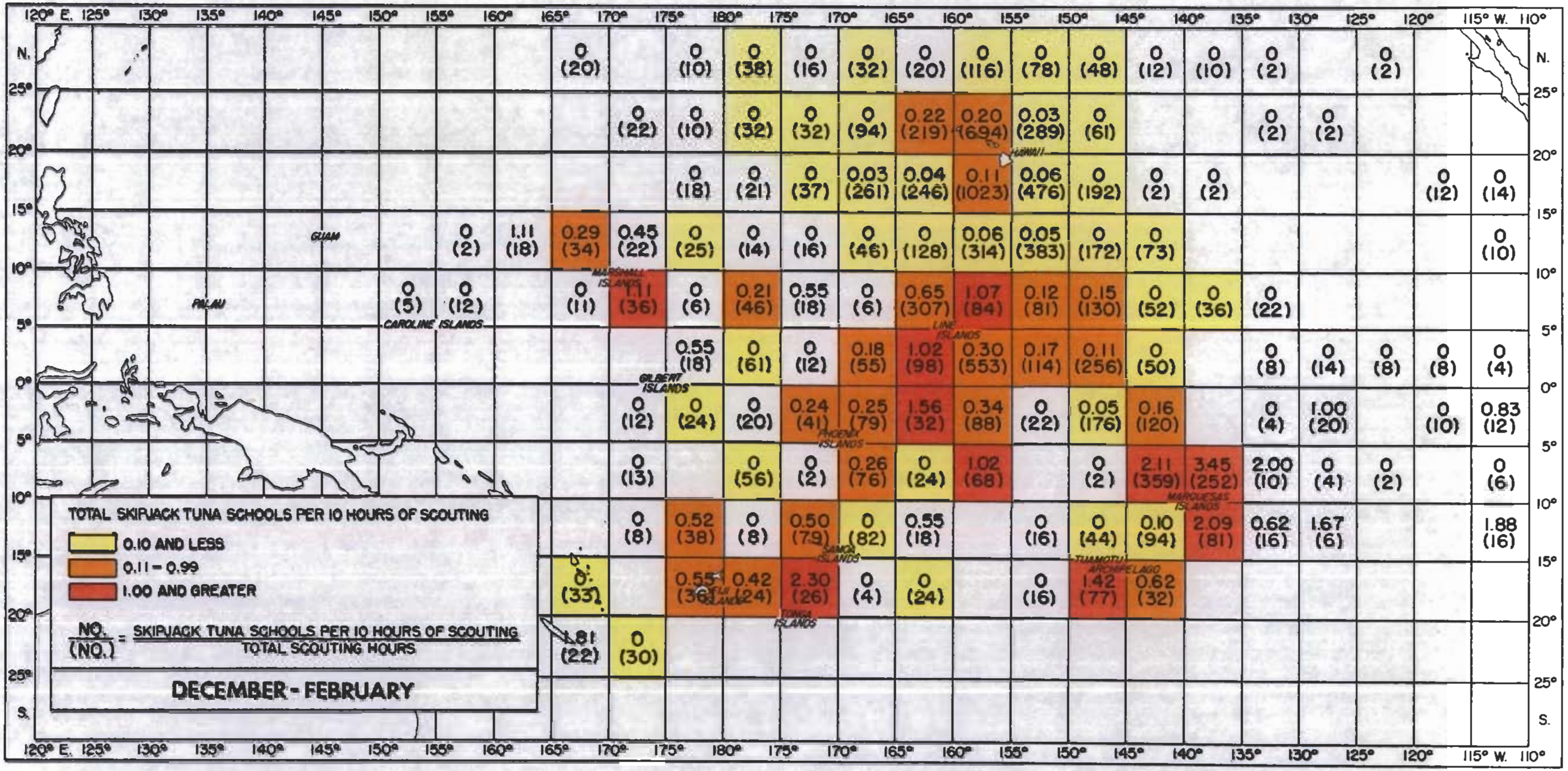


Figure 50e.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

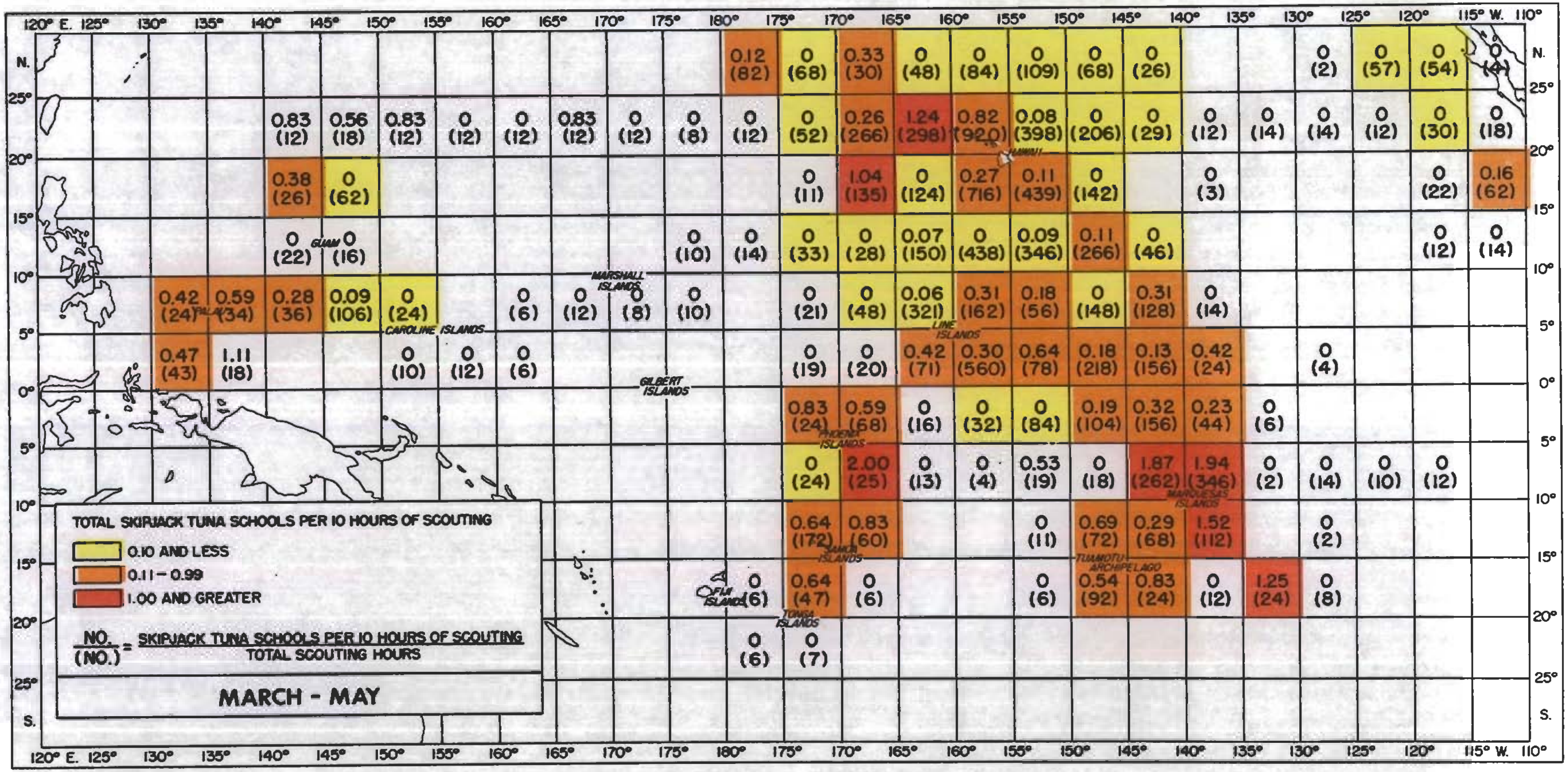


Figure 50f.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

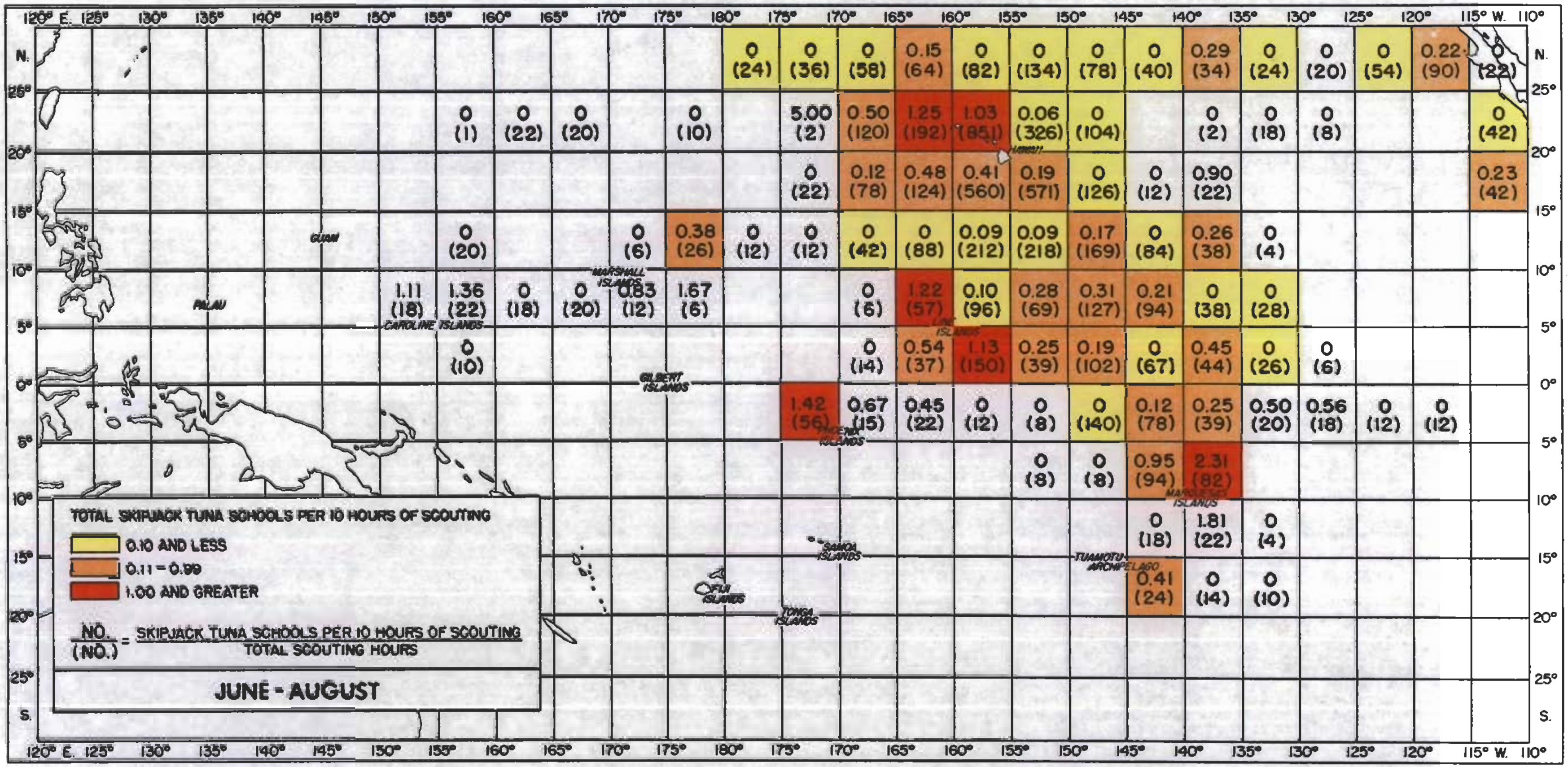


Figure 50g.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

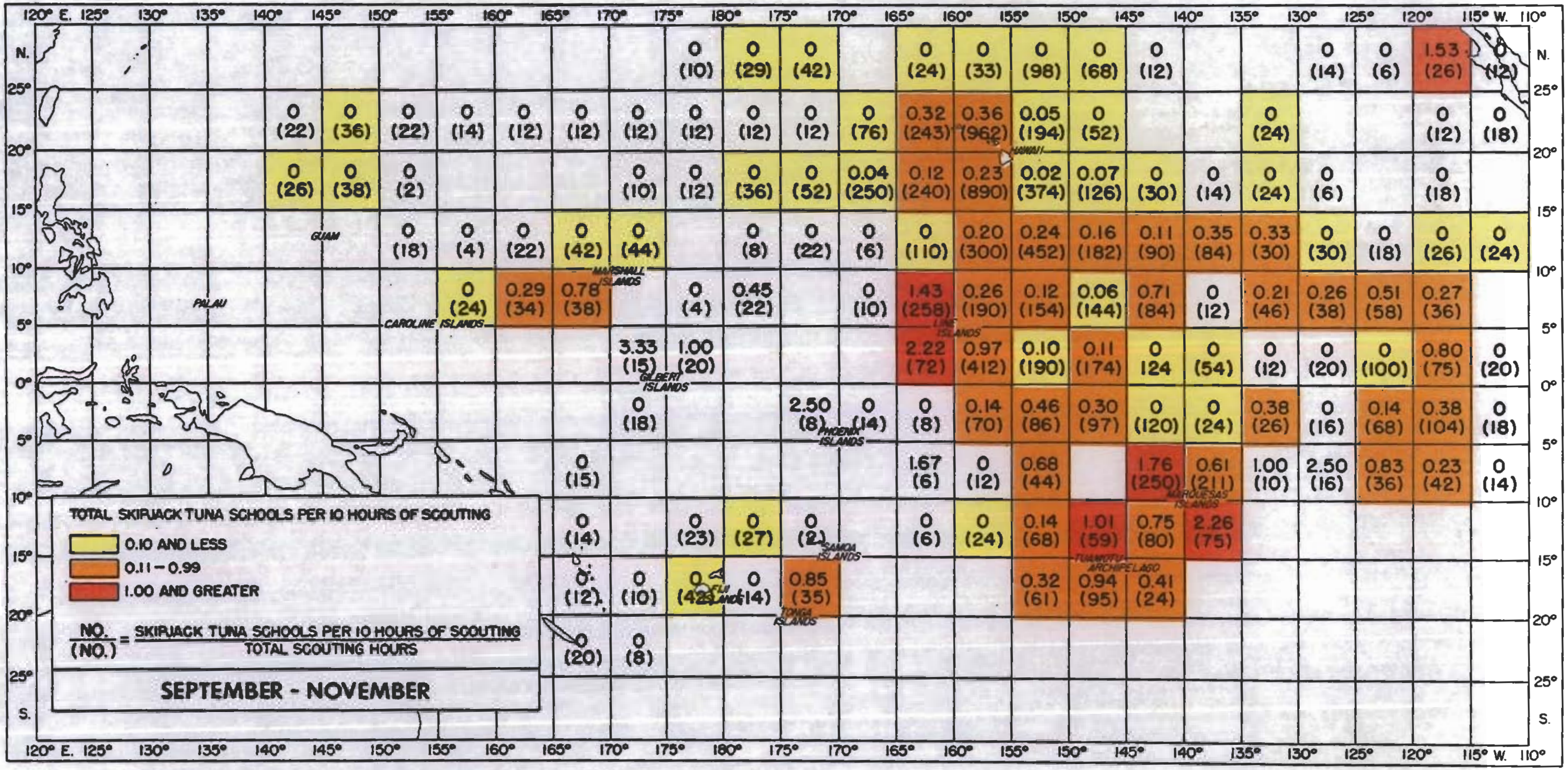


Figure 50h.--Skipjack tuna school sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

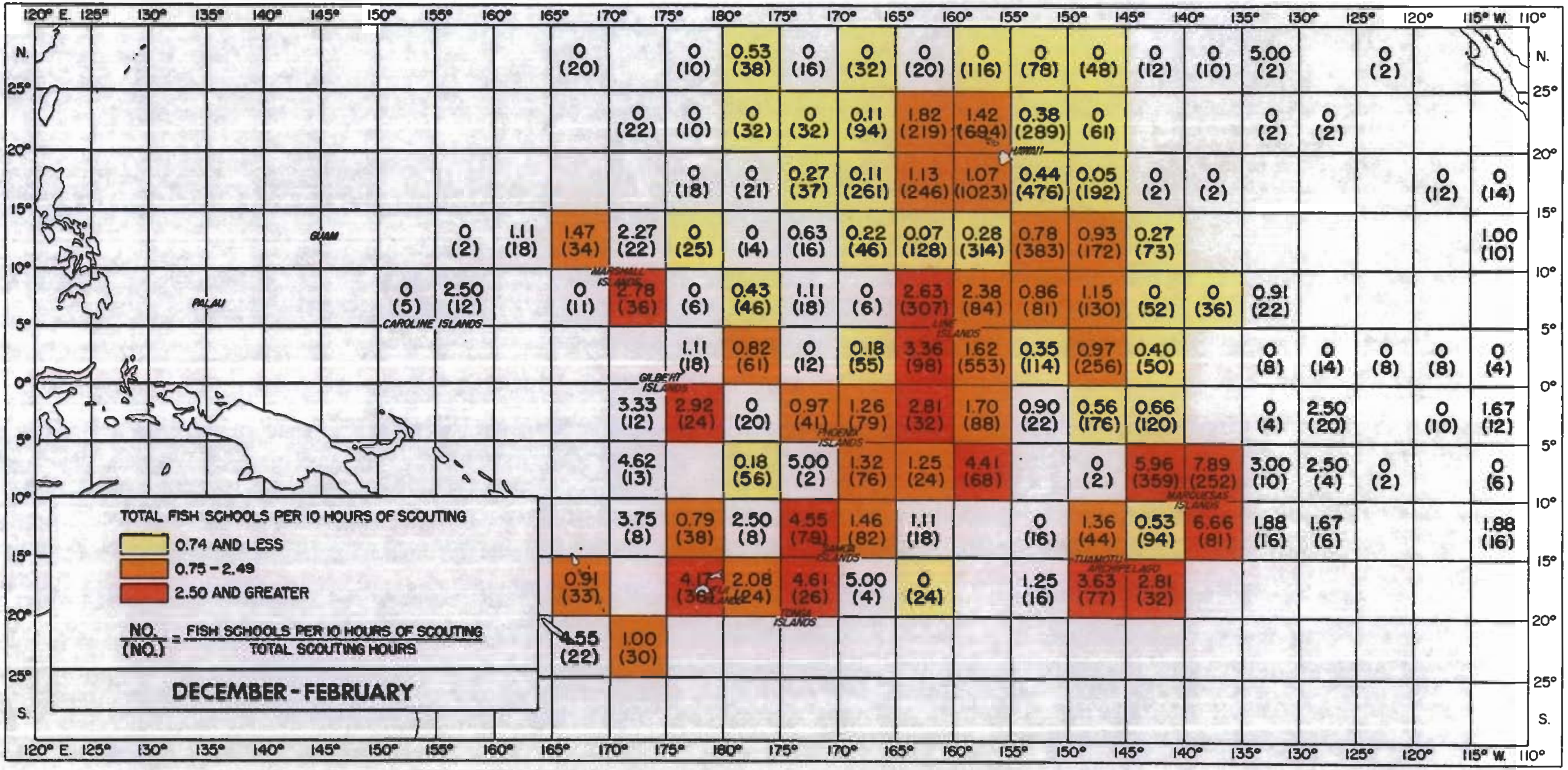


Figure 50i.--Total school sightings by National Marine Fisheries Service vessels, December-February 1950-72 (from Naughton, see footnote 5).

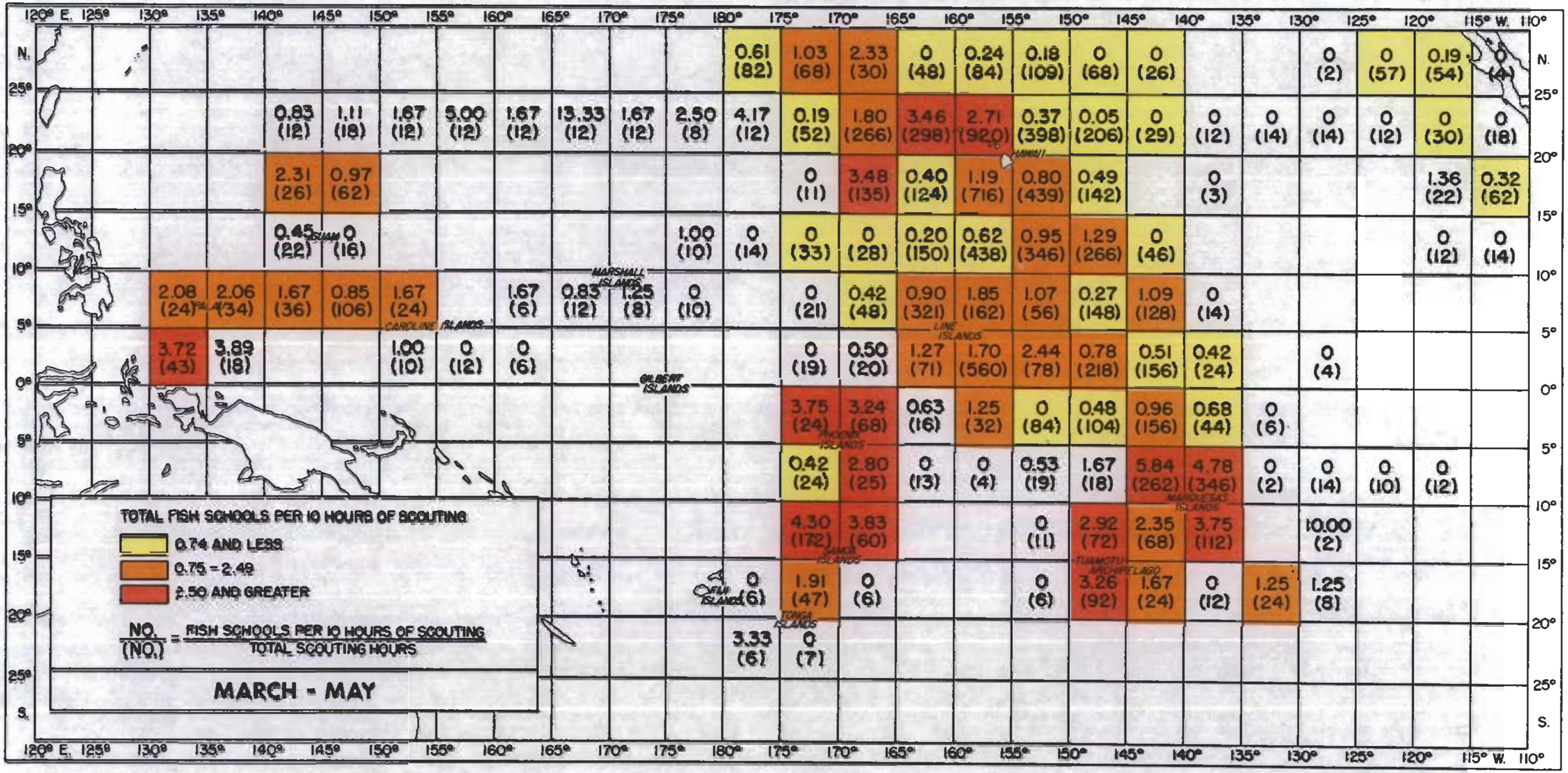


Figure 50j.--Total school sightings by National Marine Fisheries Service vessels, March-May 1950-72 (from Naughton, see footnote 5).

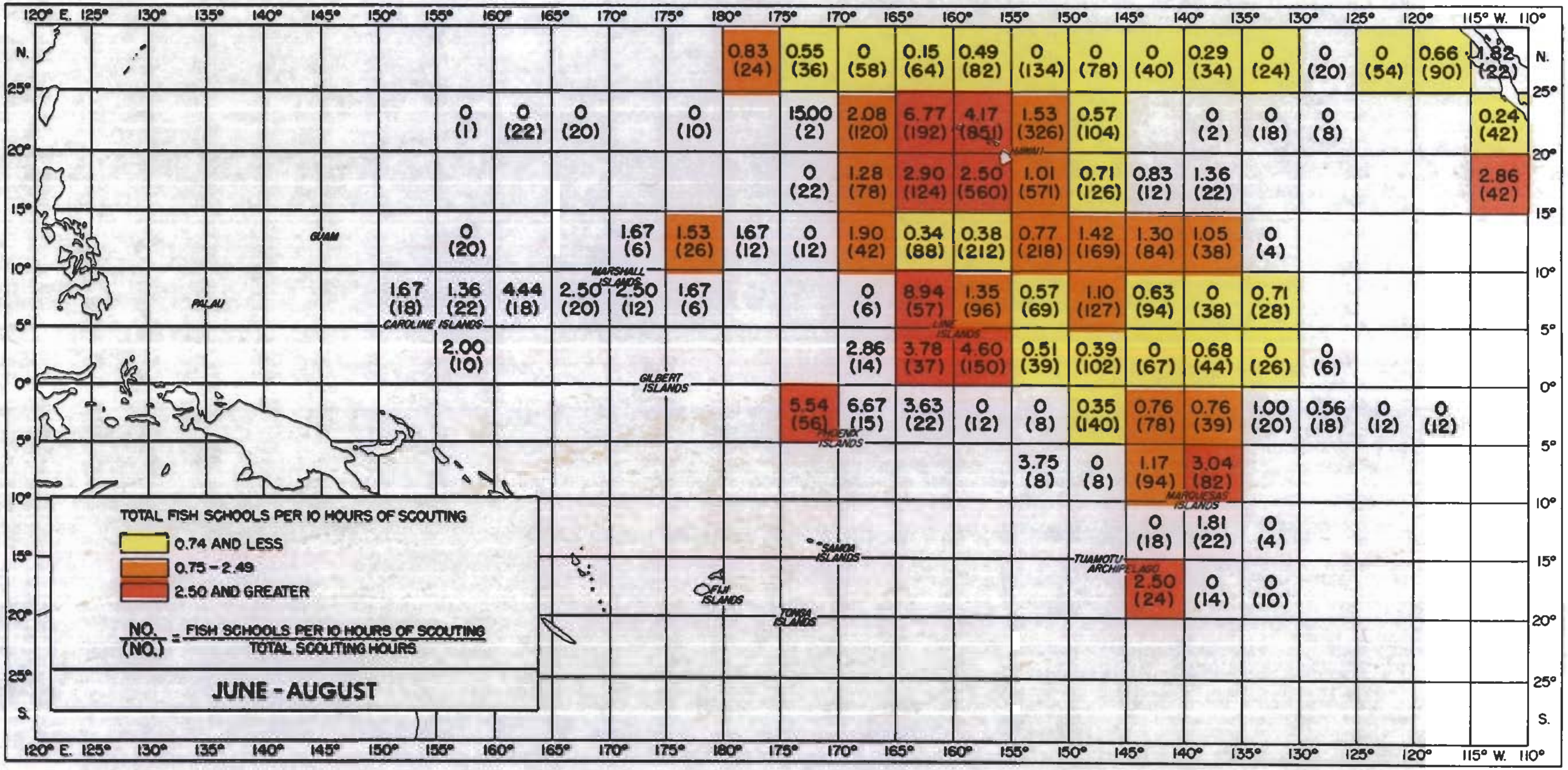


Figure 50k.--Total school sightings by National Marine Fisheries Service vessels, June-August 1950-72 (from Naughton, see footnote 5).

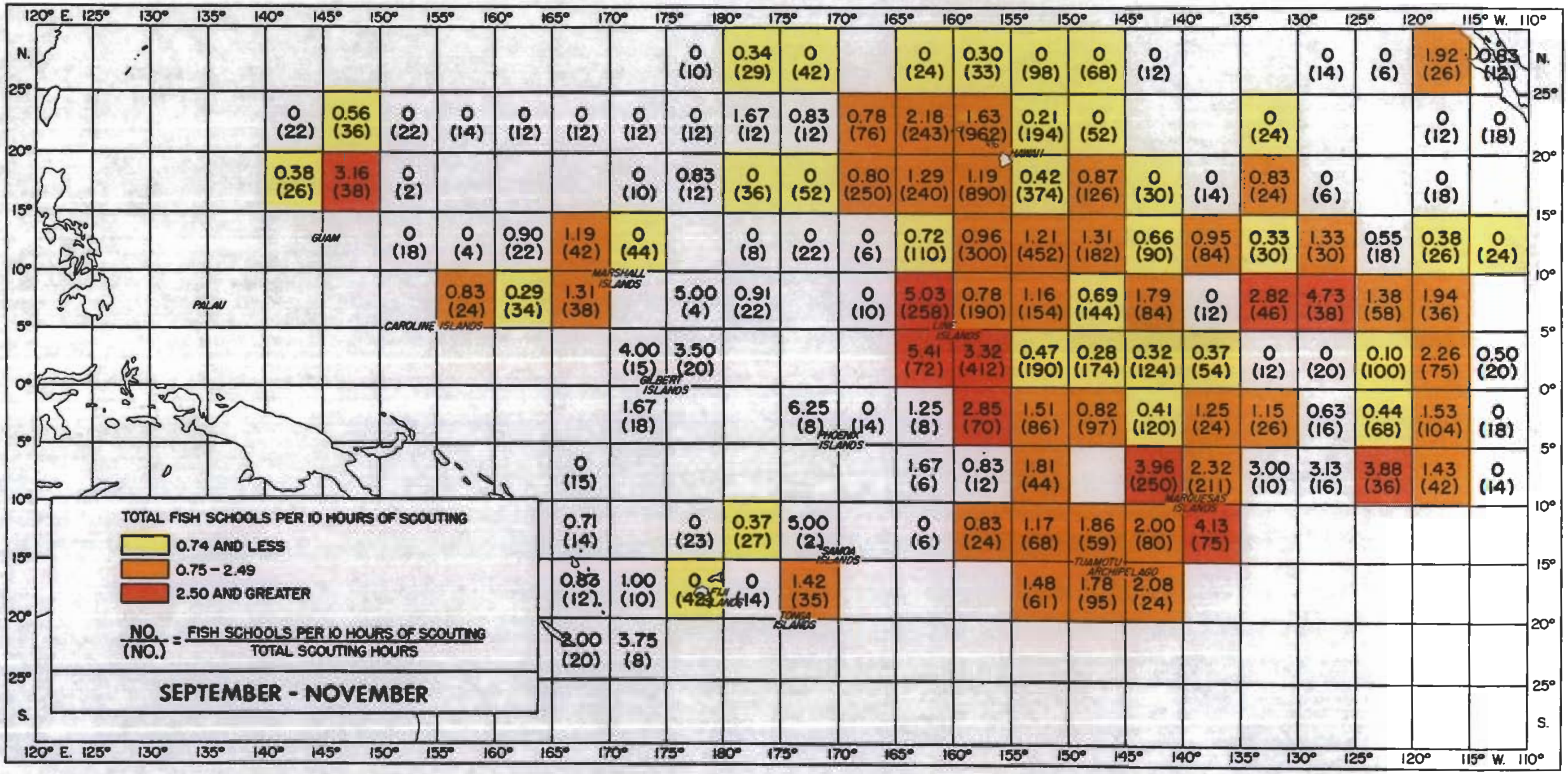


Figure 50l.--Total school sightings by National Marine Fisheries Service vessels, September-November 1950-72 (from Naughton, see footnote 5).

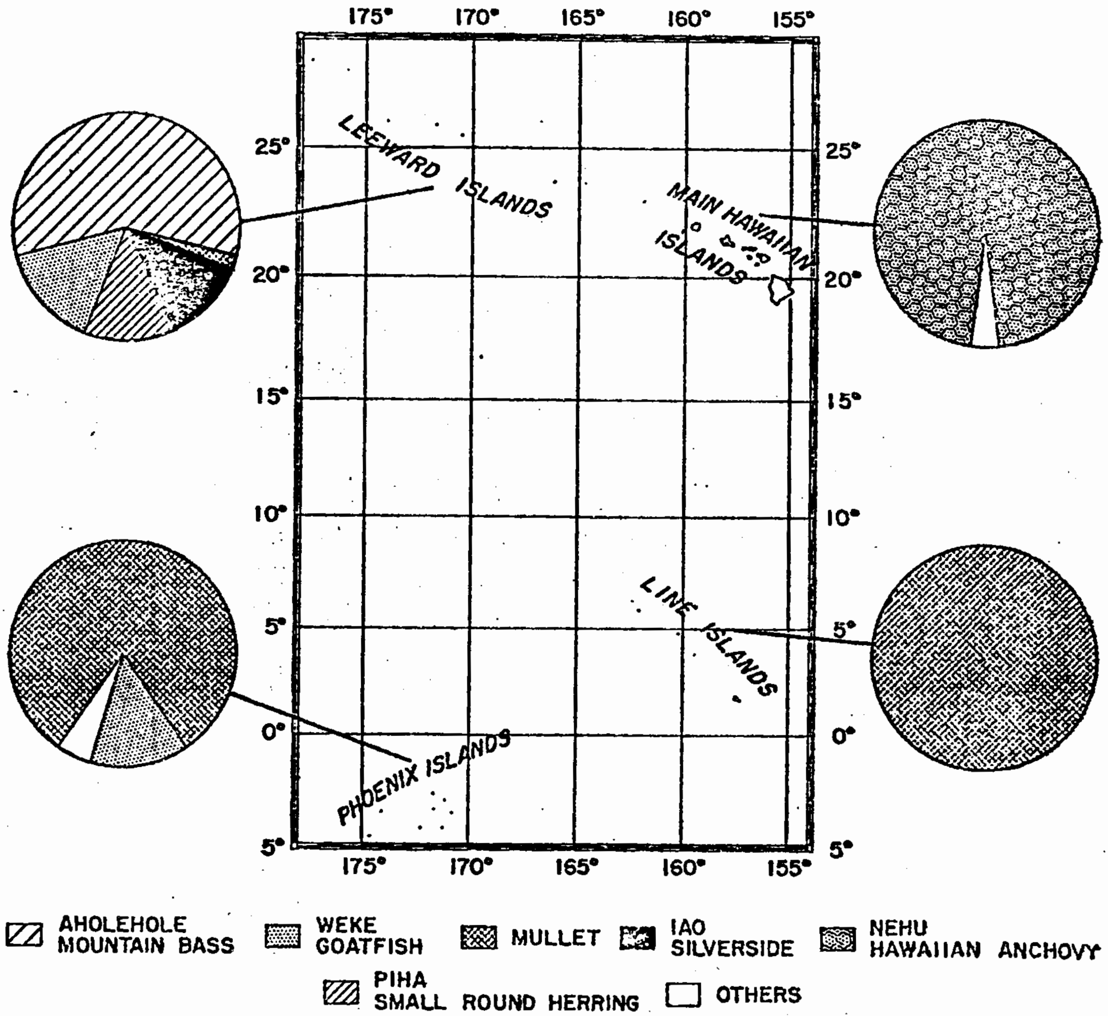


Figure 51.--Bait resources in the central Pacific islands (from Sette and staff 1954).

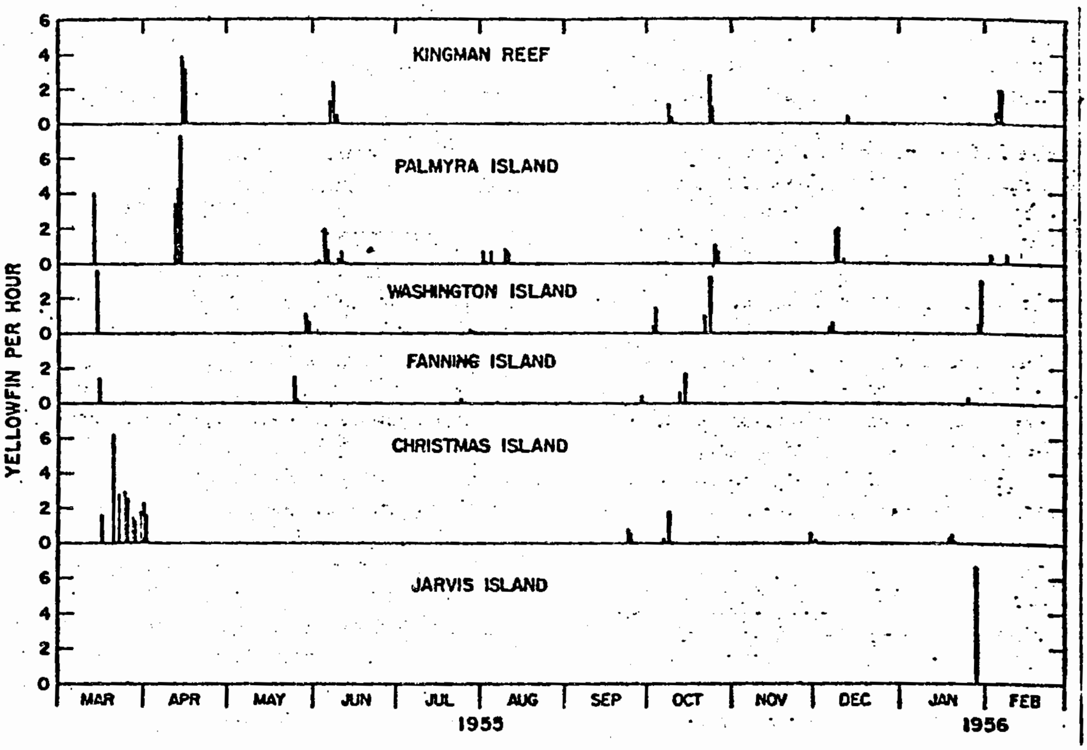


Figure 52.--Yellowfin tuna troll catch rates in the Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

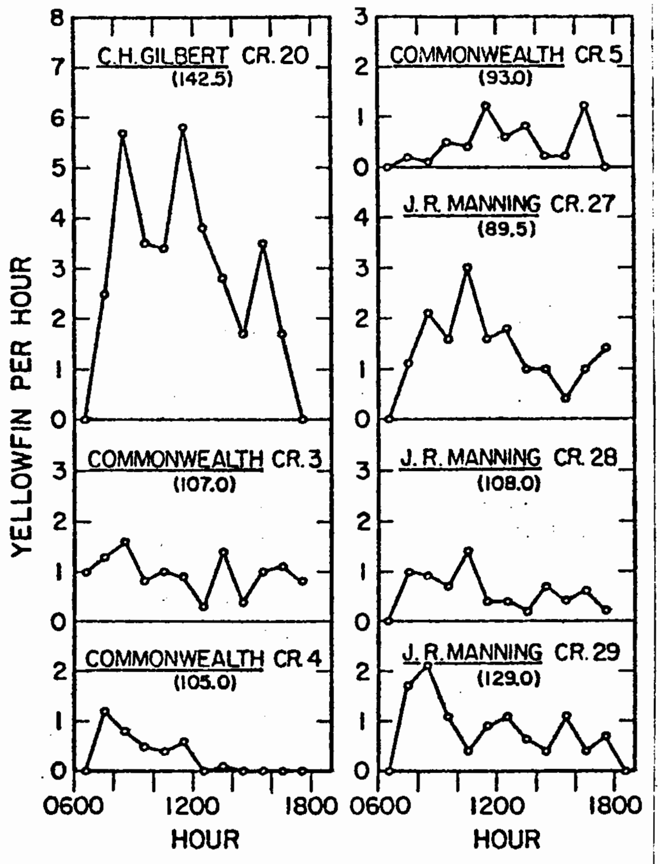


Figure 53.--Yellowfin tuna troll catch rates in the Line Islands 1955-56 arranged by time of day (data on total number of hours trolled given in parentheses) (from Iversen and Yoshida 1957).

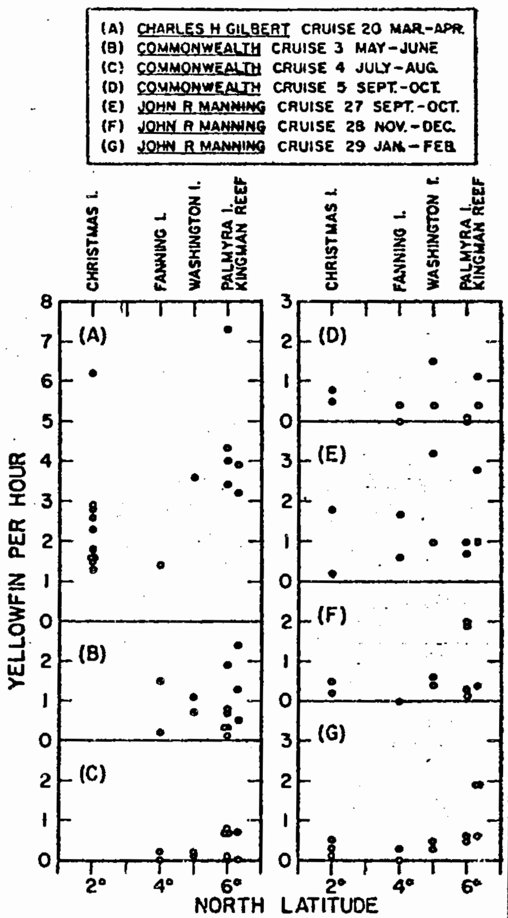


Figure 54.--Relationship of yellowfin tuna troll catch rates to areas, Line Islands, March 1955 to February 1956 (from Iversen and Yoshida 1957).

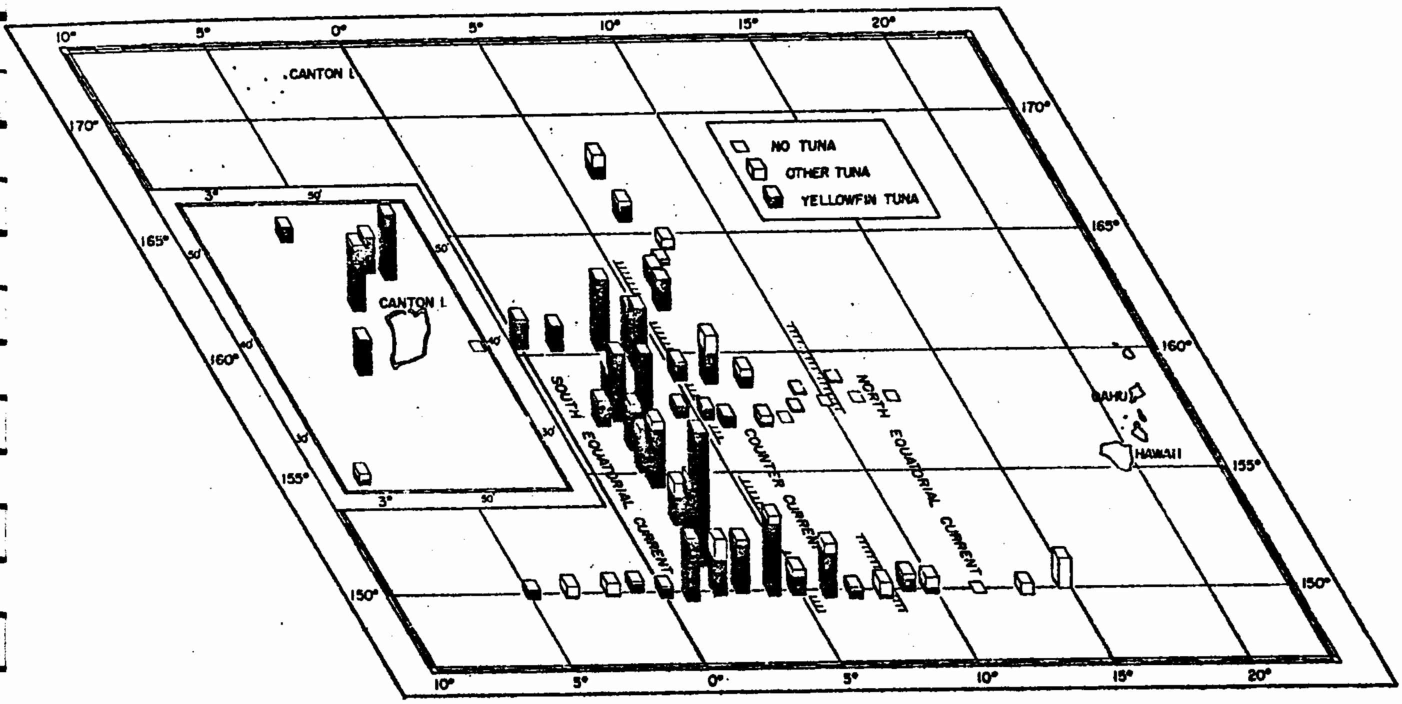


Figure 55.--Catches of tuna by Hugh M. Smith cruises 5, 7, and 11, 1950-51. The bar graphs represent tuna catch rates, yellowfin tuna shown in black, other tunas in white (from Murphy and Shomura 1953a).

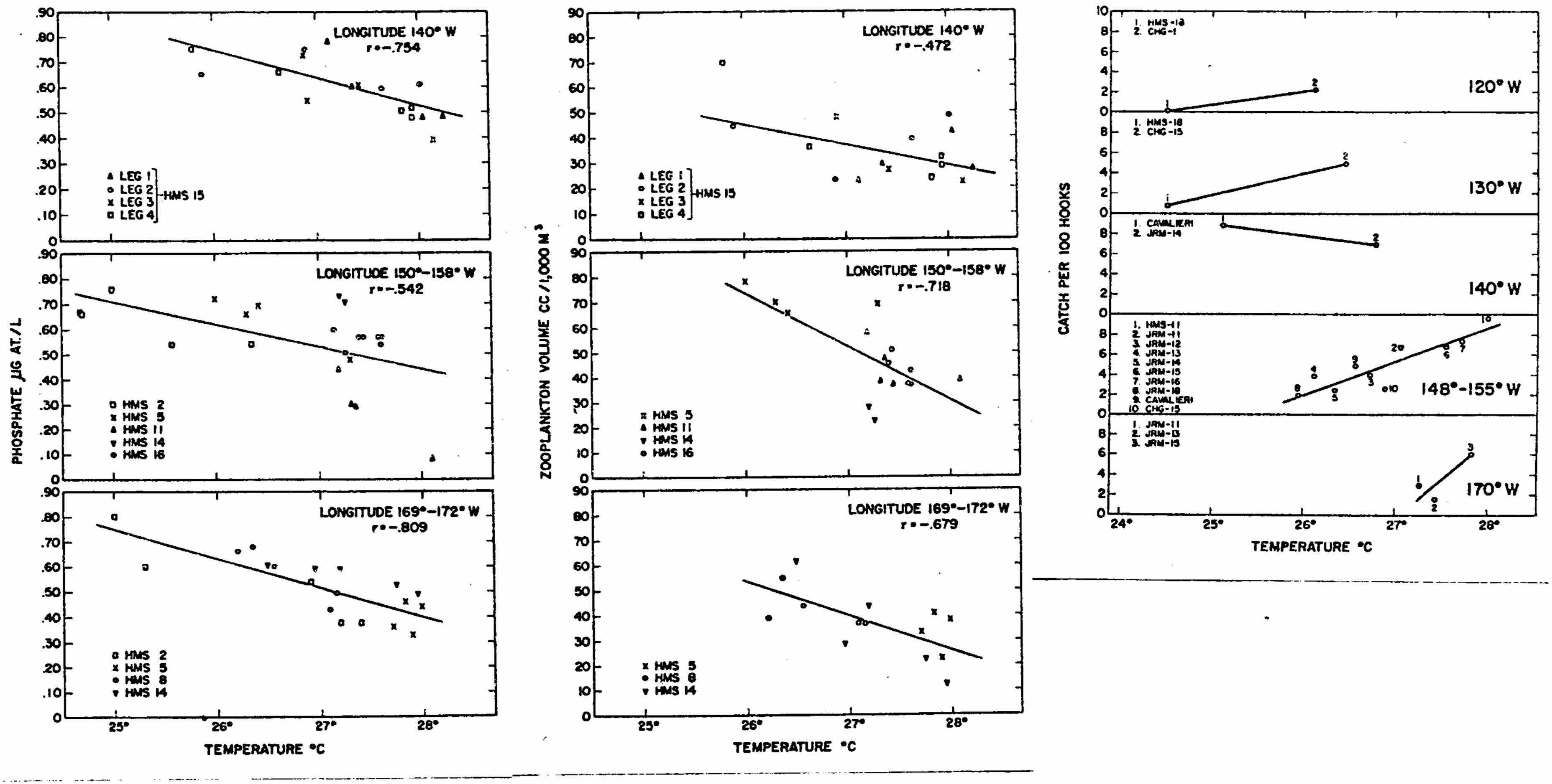


Figure 56.—Relationship between surface temperature and phosphate, zooplankton volume, and yellowfin tuna catch at several longitudes for the zone lying between lat. 1° and 5°N (from Murphy and Shomura 1972).

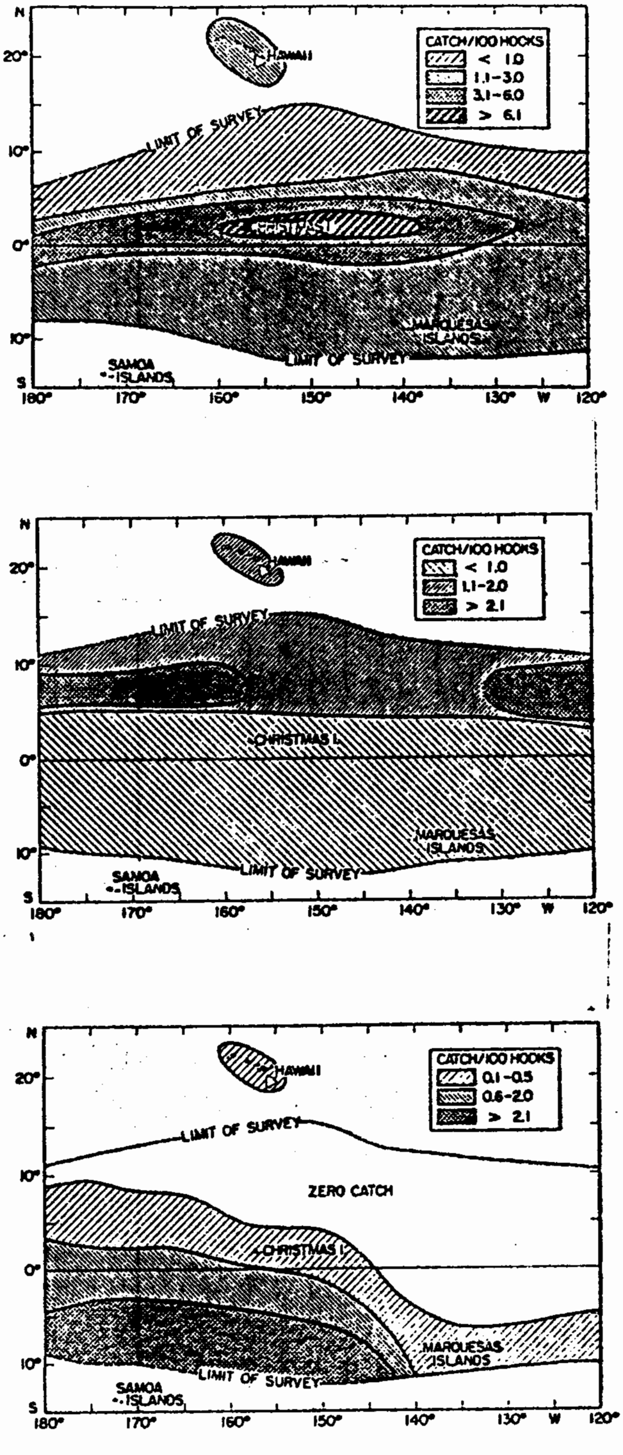


Figure 57.--The distribution of deep-swimming yellowfin tuna (top), bigeye tuna (middle), and albacore (bottom) in the central equatorial Pacific Ocean. The isograms are in units of number of fish caught per 100 hooks (from Murphy and Shomura 1972).

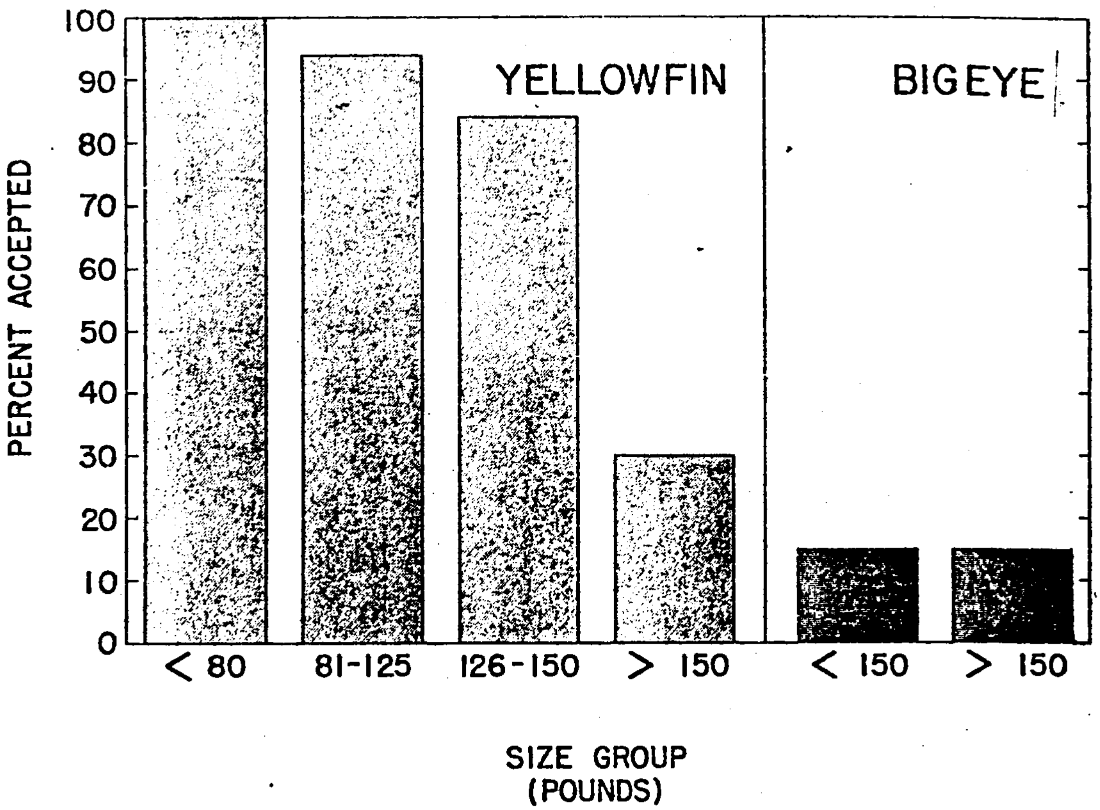


Figure 58.--Percentage of Cavalieri's longline-caught tuna acceptable for canning (from Sette and staff 1954).

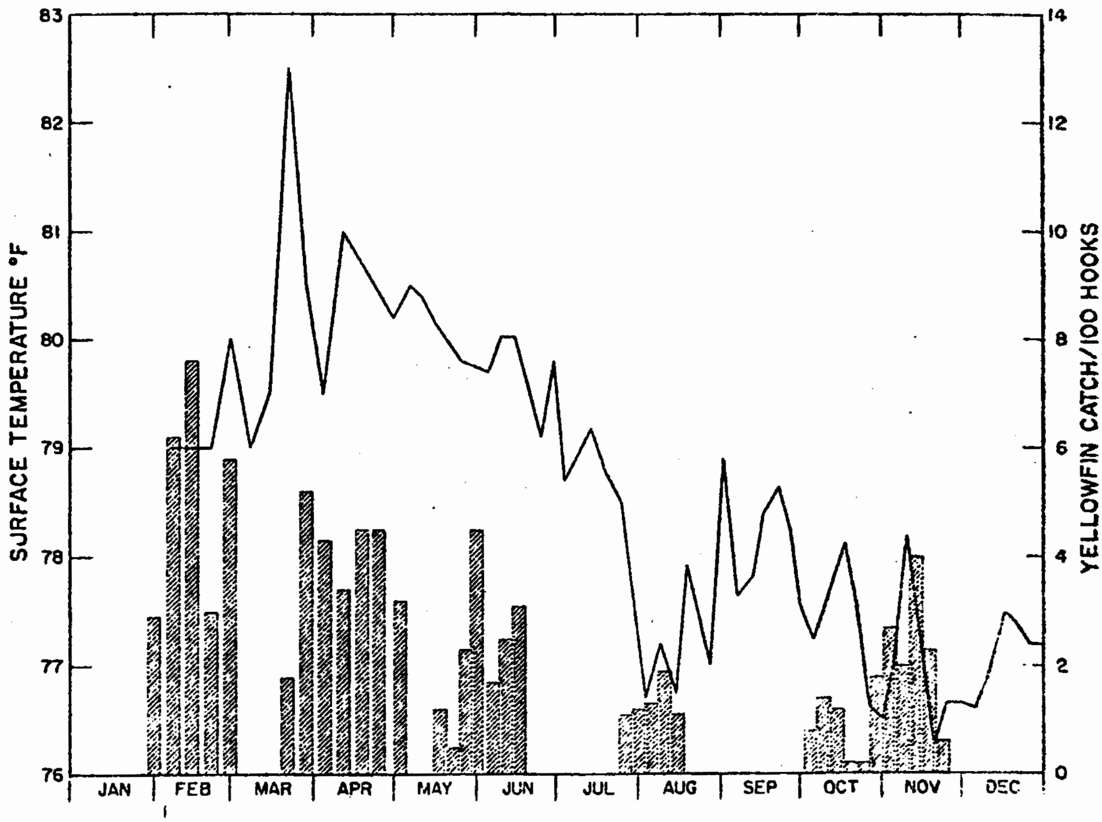


Figure 59.--Surface temperatures at Christmas Island and Line Islands yellowfin tuna catches during 1954 by 5-day periods (from Iversen and Yoshida 1956).

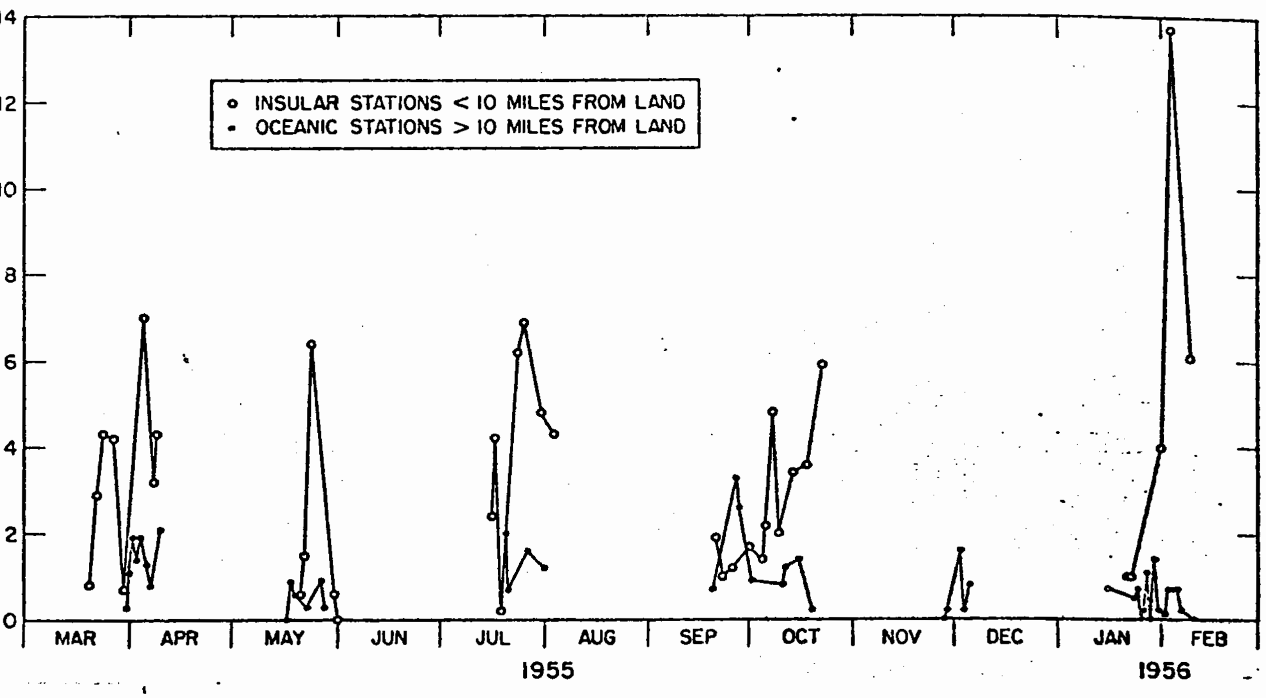


Figure 60.--Daily yellowfin tuna longline catch rates in the Line Islands, 1955-56 (from Iversen and Yoshida 1957).

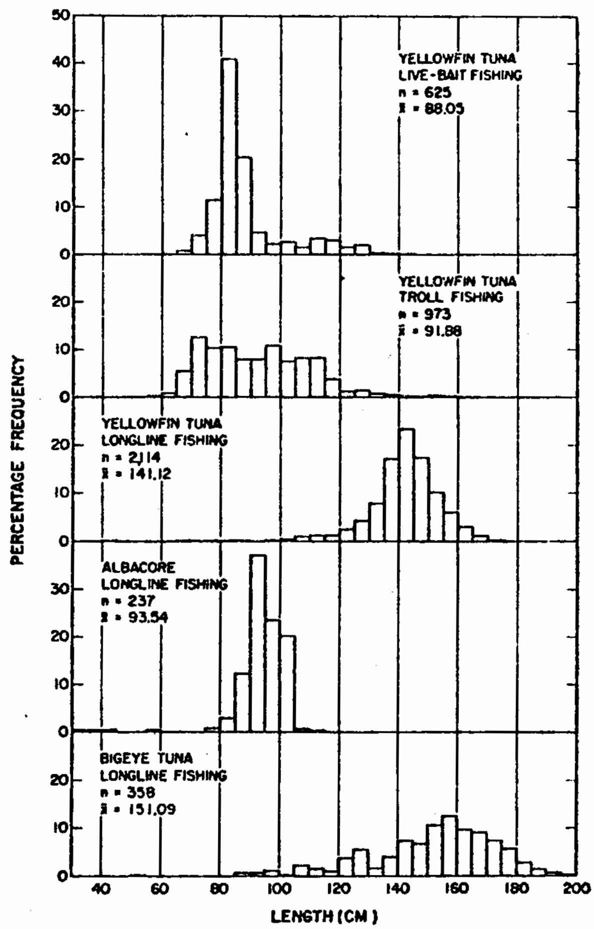


Figure 61.--Length frequencies (fork lengths) of the principal tuna species taken in the central equatorial Pacific by type of gear (from Murphy and Shomura 1972).

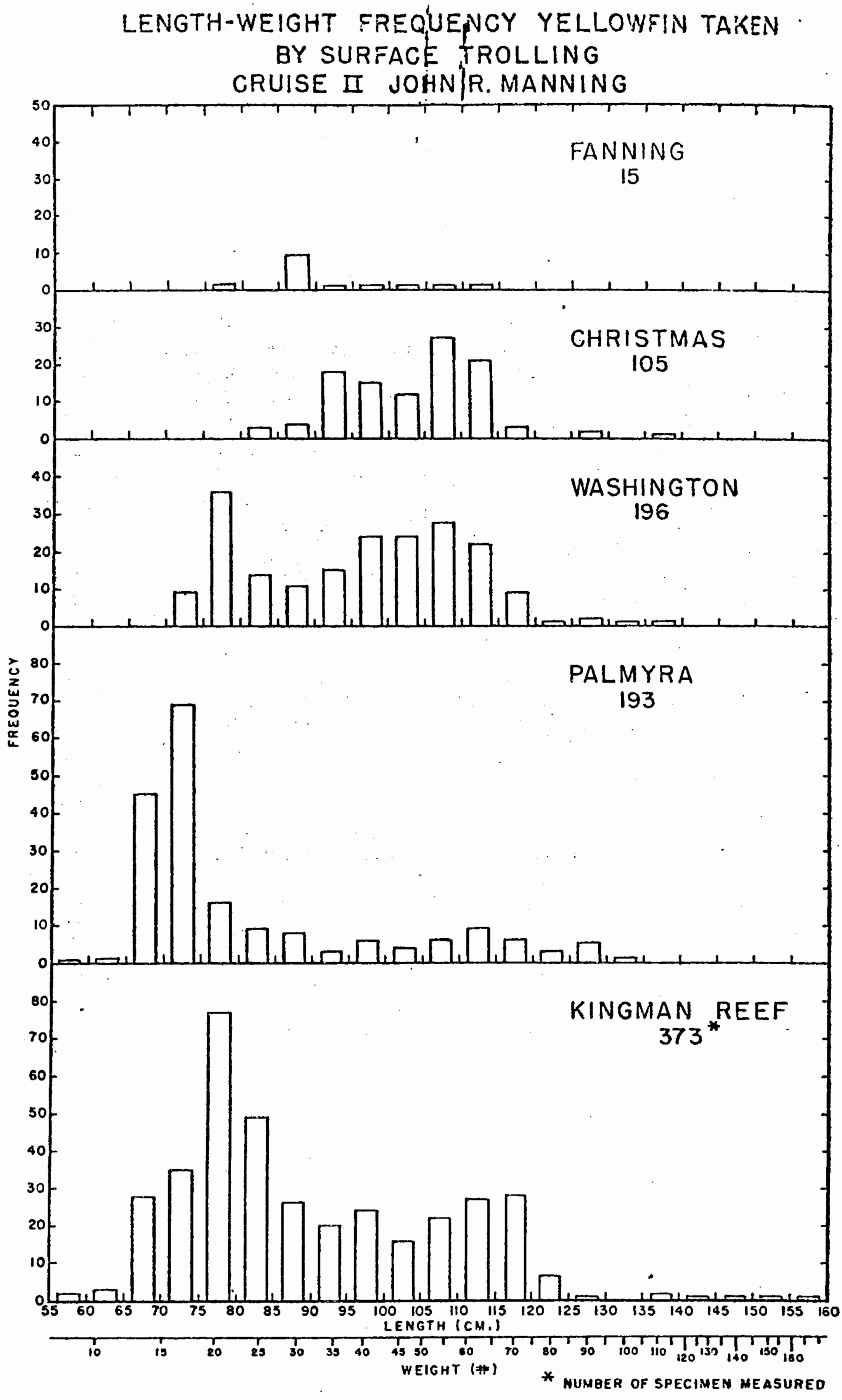


Figure 62.--Length-weight frequency distribution of yellowfin tuna caught by surface trolling in the Line Islands, 1950 (from Bates 1950).

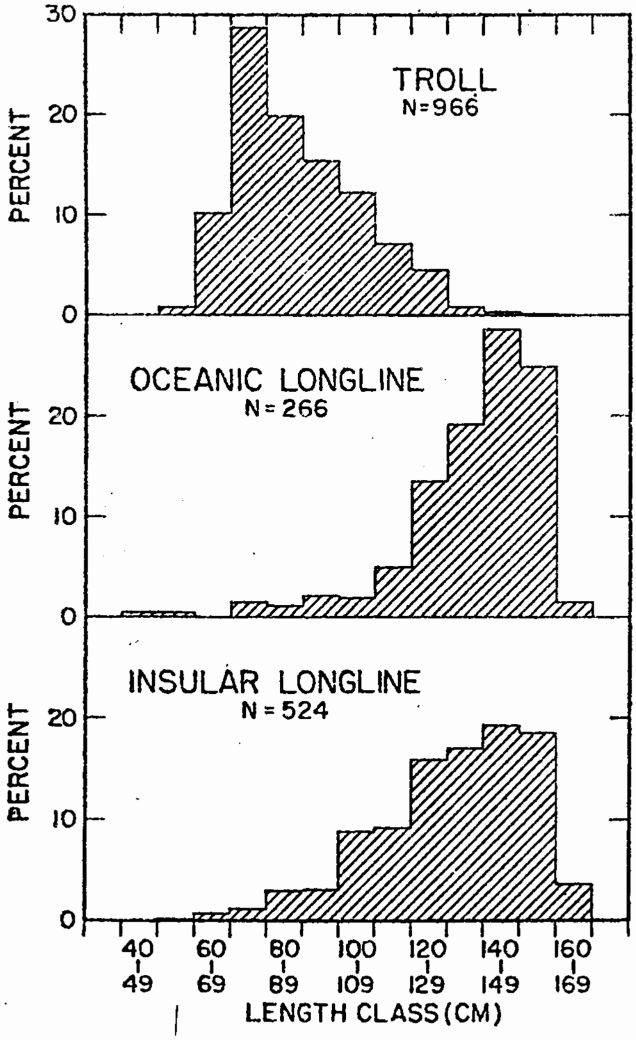


Figure 63.--Length-frequency distributions of oceanic and insular yellowfin tuna caught by longlining and trolling, January 1955 to February 1956 (from Iversen and Yoshida 1957).

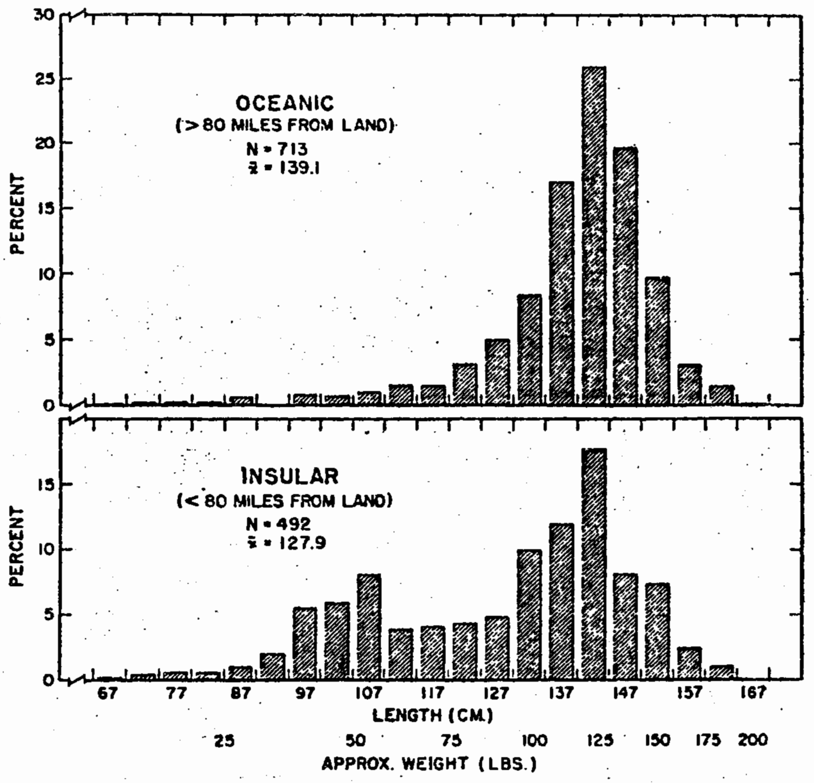


Figure 64.--Yellowfin tuna size distribution with distance from land, January-December 1953 (from Shomura and Murphy 1955).

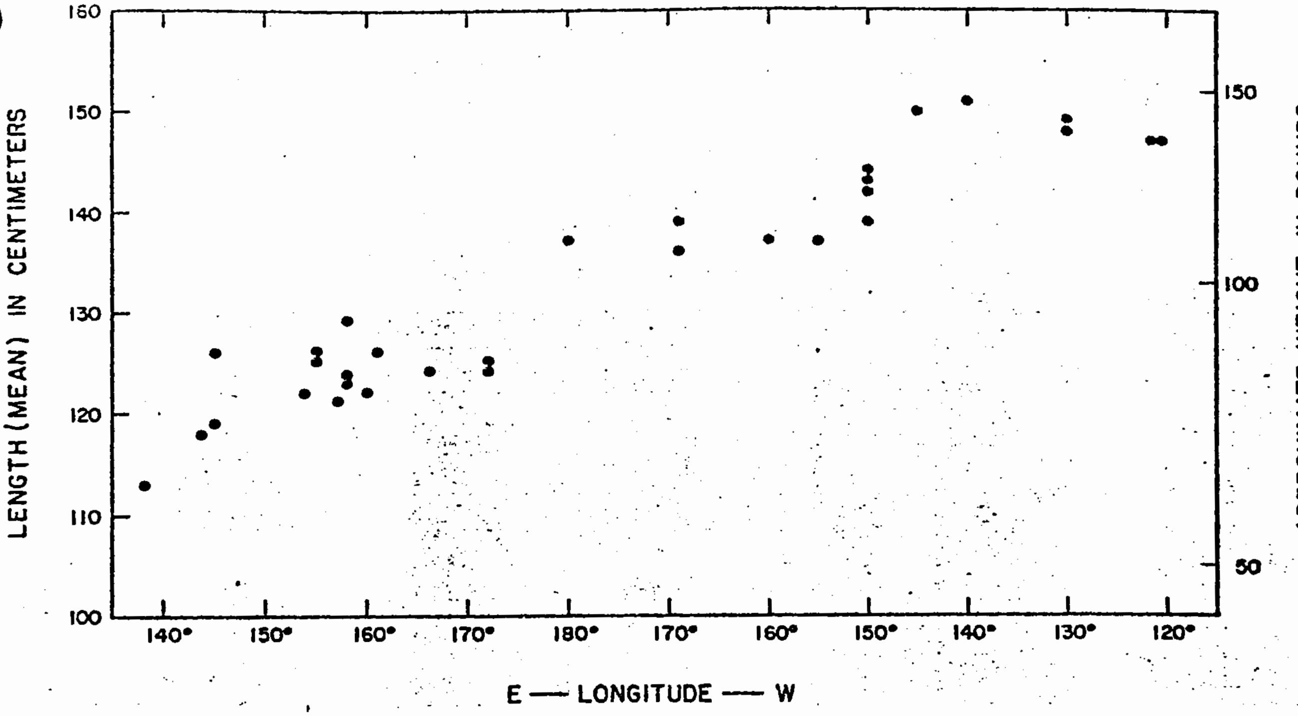


Figure 65.--Mean lengths of samples of longline-caught yellowfin tuna plotted against longitude of capture, August-November 1952 (from Murphy and Shomura 1955).

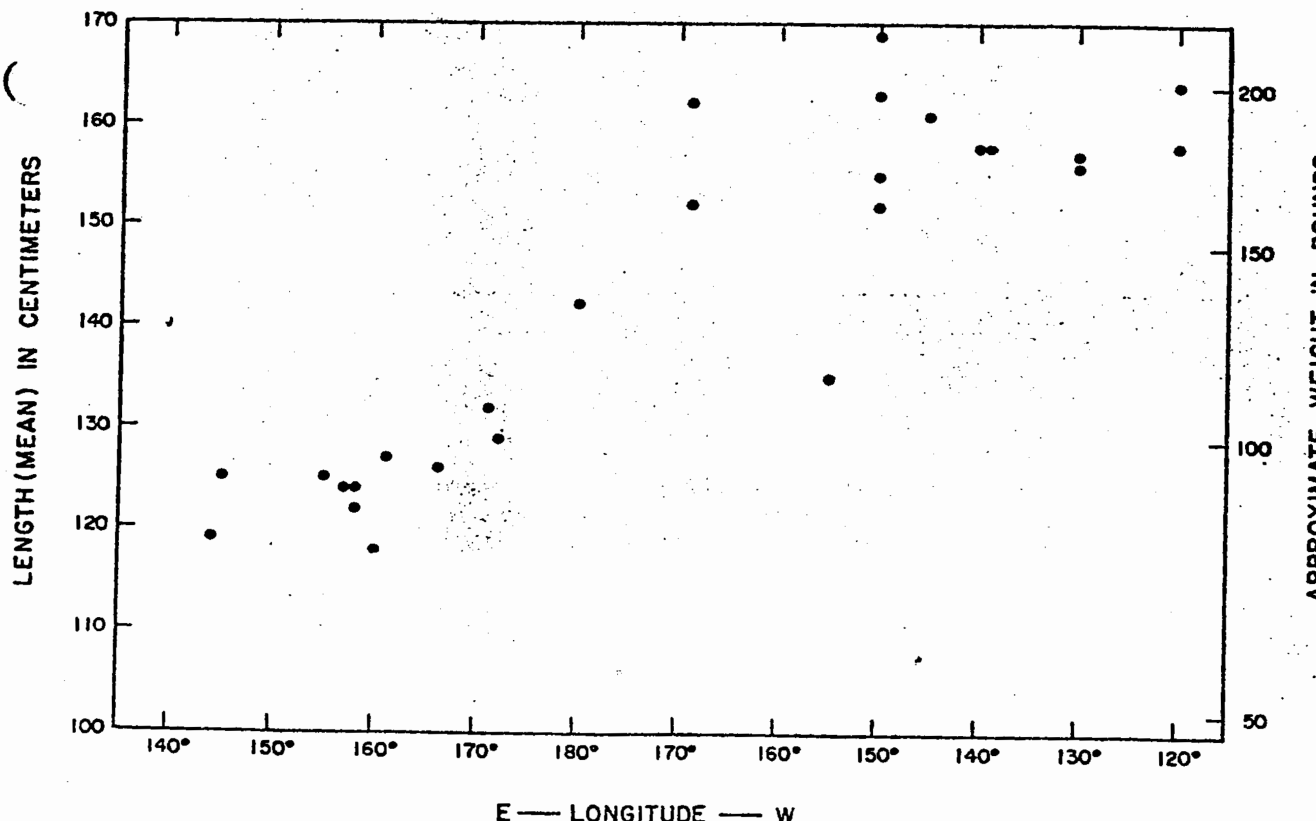


Figure 66.--Mean lengths of samples of longline-caught bigeye tuna plotted against the longitude of capture, August-November 1952 (from Murphy and Shomura 1955).

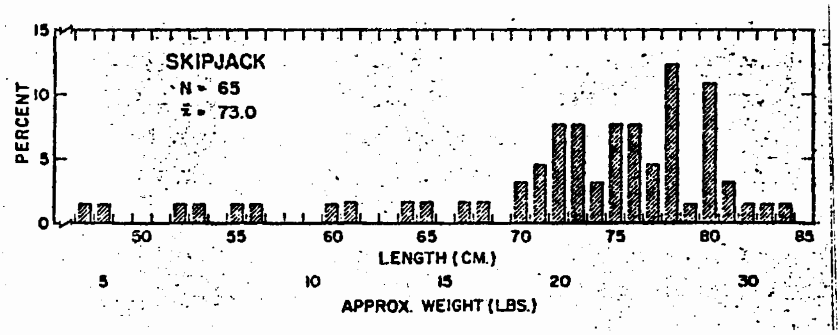


Figure 67.--Size distribution of skipjack tuna taken by longline in the central equatorial Pacific, 1953 (from Shomura and Murphy 1955).